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FUNDAMENTALS OF NOISE: MEASUREMENT, RATING SCHEMES, AND STANDARDS

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DECEMBER 31, 1971

THE NATIONAL BUREAU OF STANDARDS
under
INTERAGENCY AGREEMENT

U.S. Environmental Protection Agency
Office of Noise Abatement and Control
Washington, D.C. 20460

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Abstract

This report is intended to serve as an introduction to noise, including the inter-relationship between physical measures and psychological responses. The basic principles of sound generation and propagation are discussed as well as the measurement of both the physical attributes of noise and the effects of noise on people. The suitability and effectiveness of various noise exposure rating schemes, used to estimate or predict the effects of noise on man, are discussed and critiqued. Included are sample calculations of sound level, loudness level, and perceived noise level for five selected spectra. The need is stressed for inclusion of well-defined environmental and operational requirements into measurement procedures for those devices where the noise produced is dependent on the surroundings and the operation of the device. Also presented are a glossary of pertinent acoustic terminology and a compilation of existing standards related to noise, including a brief description of the intent and scope of each.

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1. Sound Generation and Propagation

Sound is sometimes defined as that form of vibrational energy that gives rise to the sensation of hearing. While this definition is acceptable, it is of limited usefulness in understanding how sound is generated, propagated, and perceived.

The most common physical mechanism for generating sound is the mechanical vibration of solid surfaces. Such surfaces can be excited into vibration by numerous mechanisms, such as transient or periodic impacts or oscillatory motions of equipment. Consider what happens when the sheetmetal panels of a truck hood are set into vibration due to engine operation within the enclosure. The vibrating panel moves alternately back and forth. As it moves forward, it pushes against the air nearest it. When the panel reverses its direction of motion, it produces a partial vacuum, or rarefaction, in the nearby air. The alternate compression and expansion of the air adjacent to the panels results in small local fluctuations in the atmospheric pressure. These fluctuations in turn cause a portion of the air farther away from the panel also to fluctuate in pressure. This local disturbance is thus propagated through the air in the form of sound waves that reach our ears. In addition to being generated by the mechanical vibration of solid surfaces, audible sound is frequently generated by the flow of gases, e.g., by compressed air exhausting from a pneumatic hammer or by the turbulent jet exhaust of an aircraft. Sound waves are members of a general class known as elastic waves, characterized by the fact that a disturbance initiated at one point is transmitted to other points in a predictable manner determined by the physical properties of the medium in which the wave is propagated. Sound waves can occur in many media. We are familiar with sounds that occur in air; however, sound also is transmitted in water, structures and virtually any solid, liquid or gas.

For discussing sound waves in air, it is helpful to think about two types of waves--the plane wave and spherical wave. If sound propagates in one direction only, the forward edge of the wave lies on the surface of a plane perpendicular to the direction of propagation of the wave. Measurement of the pressure fluctuations associated with a plane, or free, progressive wave is simplified because the location of the transducer (a device which translates the changing magnitude of one kind of quantity, e.g., sound pressure on a microphone, into corresponding changes in another kind of quantity, e.g., voltage) is unimportant. The sound pressure is the same everywhere in space, except for relatively small effects due to absorptive and dissipative losses in the medium. An approximation to this simple kind of wave is obtained far away from a sound source when it is placed in an acoustically free field (a field without any nearby sound reflecting obstacles).

Another type of sound wave frequently encountered in practice is the spherical wave. Such waves can be thought of as waves propagating away from a small point source with an absence of reflecting surfaces in the vicinity of the source and the point of measurement. An instantaneous picture of the pressure distribution in the forward edge of the pressure wave would show that it lies on the surface of a sphere, with the center of the sphere located at the point source. Unlike the case of plane waves, the acoustical intensity (sound power per unit area) of spherical waves decreases as the wave gets farther from the source, according to a relationship known as the inverse square law. In an ideal free field, and with no dissipation, a 6-decibel (dB) decrease in sound pressure level (a level implies relative quantities; this concept will be discussed later) could be expected for each doubling of distance. Since real conditions are not ideal, in practice some loss other than 6 dB per double-distance can be expected.

The inverse square law governs the intensity of the free sound radiation in the acoustical far field of a sound source. The acoustical far field is the region where the sound wave diverges as from a spherical source. If sound measurements are made in the far field, then the sound level farther from the source can be accurately predicted.

The range of sound pressures between the threshold of hearing (for normal young people the smallest sound pressure the human ear can sense is approximately 0.00002 N/m^2*) and the highest sound pressure to which people are exposed (the lift-off noise near a Saturn rocket is approximately 20,000 N/m^2) covers a range of 1,000,000,000 to 1. Since there is interest in observing the effects of small changes at both extremes, a linear scale would be impractical. A simple mathematical scale suited to this range of numbers is a scale based on the logarithm (to the base ten) of the relative sound pressures. The range from 1 to 1,000,000,000 would be compressed to a scale running from 0 to 9 ($\log_{10} 1 = 0$; $\log_{10} 1{,}000{,}000{,}000 = 9$). This is a system based on the number of tenfold increases rather than on the actual number itself.

The numbers 0 to 9 represent relative quantities, and the quantity measured on such a scale is referred to as a level. Scientists and engineers usually work with energy quantities that would be proportional to the square of the sound pressure rather than to the sound pressure itself. This presents no difficulty, since the logarithm of a squared number is two times the logarithm of the original number; therefore, instead of a range of levels from 0 to 9, the range runs from 0 to 18 for sound pressure squared. The unit on this scale is called a bel. The bel has been divided into 10 smaller units known as decibels, so that the range of sound pressures, from approximate threshold of hearing to Saturn rocket noise, runs from 0 to 180 decibels.

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*1 newton per square meter (N/m^2)$\approx 10^{-4}$ pounds per square inch (lb/in^2)

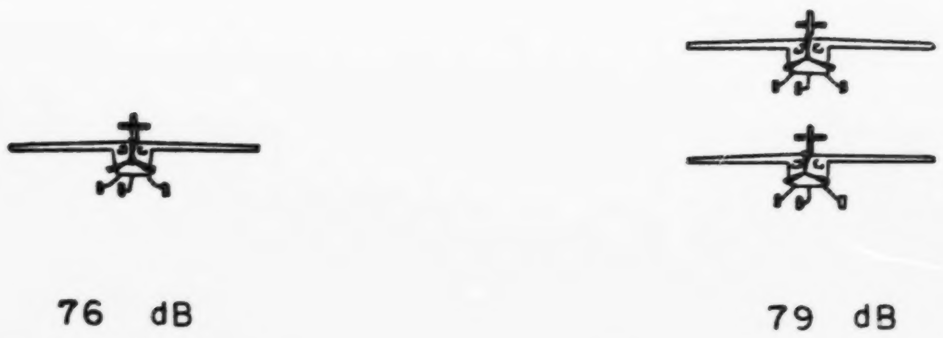

Figure 1. Doubling the number of identical sources results in a 3 dB increase in sound pressure level.

Decibel scales provide a convenient notation to describe the great ranges of both sound pressure and sound power (the time rate of flow of sound energy). The reference levels and relations for these two quantities are as follows:

$$\text{Sound Pressure Level (SPL)} = 20 \log \frac{P}{.00002} \text{ dB relative to } .00002 \text{ N/m}^2,$$

where

P is the root-mean-square sound pressure in newtons per square meter.

$$\text{Sound Power Level (PWL)} = 10 \log \frac{W}{10^{-12}} \text{ dB relative to } 10^{-12} \text{ W},$$

where

W is the acoustical power in watts.

The decibel scale is extremely useful; however, it can be puzzling since the mathematical operations differ from those to which we are accustomed through normal use of linear scales. On a linear scale, the total sound power generated by two identical noise sources would be twice the sound power of one of the sources operating alone. However, on a logarithmic scale the total sound pressure level resulting from two identical noise sources would be 3 dB higher (Figure 1) than the level produced by either source alone. (If you double a number, its logarithm will always go up by 0.3; 0.3 bels = 3 decibels). If two sound sources whose levels differ by more than 10 dB are added together, the resultant level will be less than 0.5 dB higher than the level produced by the greater source operating along.

In addition to responding to the magnitude of sound pressure, the human ear is sensitive to the frequency of the sound. The frequency region corresponding to the frequency range of the normal human ear -- 20 to 20,000 Hertz (1 Hertz (Hz) = 1 cycle per second) -- is referred to as the audio region. In reality, the human hearing range varies from person to person, depending on age, possible hearing loss, and physiological conditions. Other regions exist below and above the audio region. These are referred to as the infrasonic range (20 Hz and below) and the ultrasonic range (20,000 Hz and above). Explosions, rocket engines, and various natural phenomena generate sounds in the infrasonic range, while a portion of the noise generated by jet engine and rotary machinery and sounds used by porpoises and bats for guidance and communication are in the ultrasonic range.

Vibration, which is the term used to describe aperiodic or steady-state periodic motion, is closely related to sound. The mechanical vibration of a solid surface is a common physical mechanism for generating noise. Hence, the process of quieting a machine or device often includes a study of the vibrations involved.

Conversely, high-energy acoustical noise, such as that generated by powerful jet or rocket engines, can produce vibrations which may lead to deleterious effects such as fatigue failures of structural elements or malfunction of vital, sensitive control equipment. Such problems tend to be most serious for very intense noise sources or for lightweight structures, both of which exist in the case of aircraft.

Vibratory motion may be simple harmonic motion such as that of a pendulum, or it may be complex like a ride on the "whip" at an amusement park. Many important mechanical vibrations lie in the frequency range from 1 to 2000 Hz; however, both higher and lower frequencies are important. In seismological work vibration studies may extend down to a small fraction of a hertz, while in loud speaker cone design the vibrational frequencies of interest go up to 20,000 Hz.

Most vibrational problems which occur in machines and operations are complex in nature and vary in both frequency and amplitude in a random fashion. Because of this random pattern, detailed analysis is needed to characterize vibrational sources.

Three quantities are of great interest in vibrations--(1) displacement or magnitude of the motion, (2) velocity which is the time rate of change of displacement, and (3) acceleration which is the time rate of change of velocity. Since all three of these quantities are interrelated by differentiation or integration, the selection of a quantity to measure does not matter significantly. The most versatile transducer, due to its small size, weight, and broad frequency response is the acceleration sensitive transducer--the accelerometer. During the past ten years the accelerometer has become more popular due to the need to measure vibrations of a point rather than of an area and because the response of the test specimen is subject to change due to the added mass of the transducer itself. Velocity and displacement sensitive transducers or pickups are available; however, they have size, weight, frequency range, and phase shift limitations.

In order to control mechanical vibrations, it is necessary to isolate the source from its supporting structure. For example, high tonnage presses, drop hammers, and other high impact machines create vibrations in addition to airborne noise. These vibrations, unless well-isolated, can be transmitted throughout an entire building. Such vibration reduction measures must be given high priority for not only may there be excessive wear, inefficient performance or even fatigue failure of the machine but also man may be annoyed, fatigued, have his performance interfered with or he might actually be injured due to a vibrational problem which was given little or no attention.

2. Physical Measurement of Sound

A basic instrumentation system for measuring sound consists of (Figure 2):

1. A transducer
2. An electronic amplifier and calibrated attenuator for gain control
3. A readout device

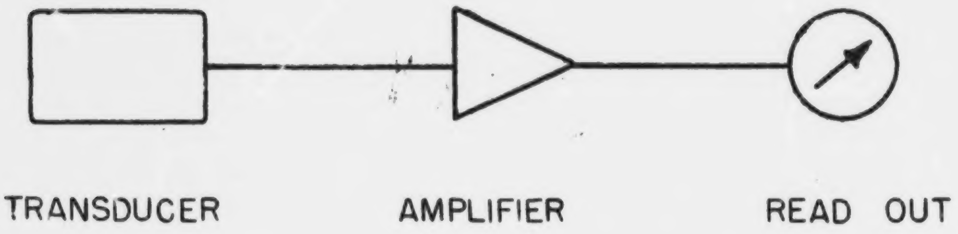

Figure 2. Basic measurement system.

The most commonly used instrument containing these components is the familiar sound level meter, a block diagram of which is shown in Figure 3. In addition to the basic components described above, the sound level meter also contains weighting networks that give greater importance to sounds in certain frequency ranges. A typical sound level meter contains three different response weighting networks, designated as A, B, and C (International Electrotechnical Commission (IEC) Recommendations 123 and 179 and American National Standards Institute Standard S1.4-1971). Recently a new weighting curve--the D curve--has been proposed for measuring jet aircraft noise. At this time, the D curve is being considered by the IEC committee. Figure 4 shows the four weighting curves. The rationale for the weighting network stems from the fact that the apparent loudness we attribute to sound varies with the sound pressure and its spectral content--the frequencies of the components of the sound. This effect is taken into account to some extent through the use of the weighting networks.

The most commonly used sound level utilizes the A-weighting network. The A-network enables the sound level meter to have a response approximating the 40-phon equal loudness contour (loudness contours are discussed later in this report). The A-weighted sound level is emerging as the measure most often utilized in objective and subjective studies of noise.

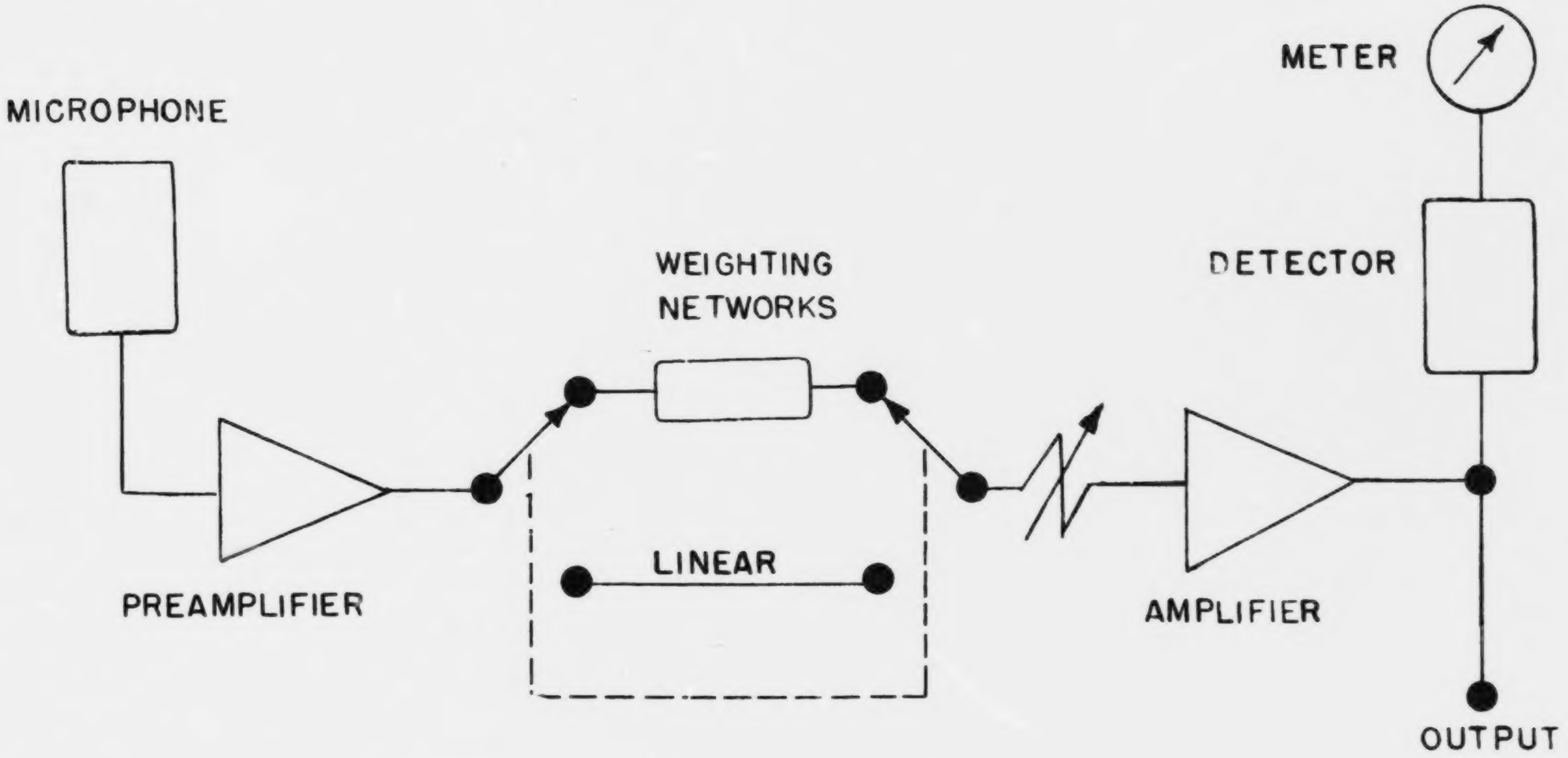
MICROPHONE
PREAMPLIFIER
WEIGHTING
NETWORKS
LINEAR
AMPLIFIER
METER
DETECTOR
OUTPUT

Figure 3. Block diagram indicating the typical internal arrangement of a sound level meter.

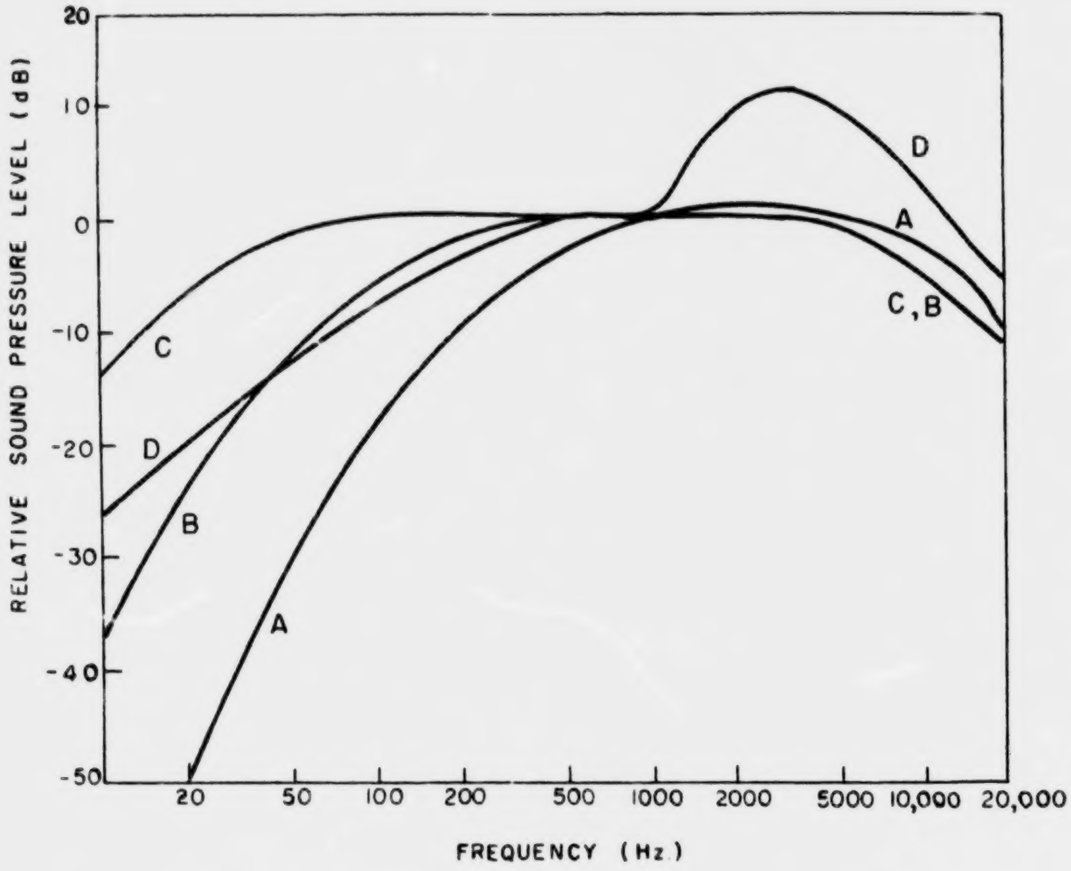

Figure 4. IEC Standard A, B, and C weighting curves for sound level meters. Also shown is the proposed D weighting curve for monitoring jet aircraft noise. From the curves it can be seen that for a 50 Hz pure tone the reading on the A scale (which discriminates against low frequency sounds) would be 30 dB less than the C scale reading.

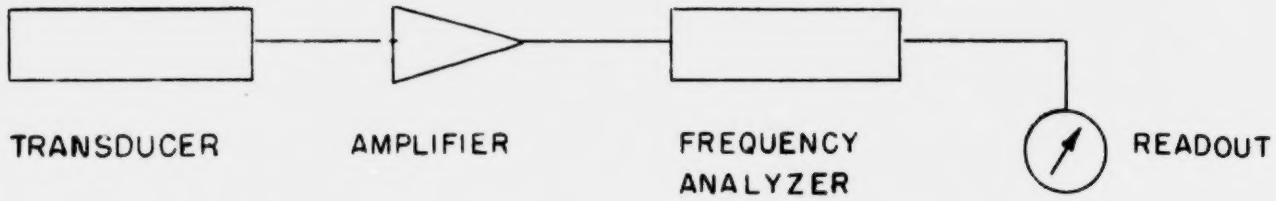
TRANSDUCER
AMPLIFIER
FREQUENCY ANALYZER
READOUT

Figure 5. Basic measurement system for performing frequency analysis.

To determine the distribution of the sound pressure level over the frequency range, a spectrum analyzer is added to the basic measurement system (Figure 5). A spectrum analyzer is basically an electrical filter set. The filters allow components in a given frequency band to pass relatively unattenuated, while attenuating components in other frequency bands. The most common type is the octave band analyzer, in which the frequency range is divided into octave bands, each of which covers a 2-to-1 range of frequencies, the center frequency of which is the geometric mean of the low and high cutoff frequencies. For example, for a center frequency of 1000 Hz, the lower cutoff frequency is 707 Hz, while the upper cutoff frequency is 1414 Hz. The range between 707 Hz and 1414 Hz is known as the bandwidth of the filter. If more detailed frequency information is required, one-third octave or narrower band filters can be utilized. Very narrow band analysis is usually only necessary for diagnostic testing and for characterizing sources producing pure tones.

Many times, suitable field analysis equipment is not available for real time analysis. In such cases there is a need to record the signal information on magnetic tape so that the original event can be recreated in the future. Tape recorders also provide the ability to make aperiodic signals, e.g., a truck passby, appear periodic. A spectrum analysis of an aperiodic signal can be performed by recording the aperiodic signal on tape and then repeating it in its entirety at some periodic interval. This is accomplished by locating the aperiodic signal on tape, cutting this section from the reel, and splicing it together to form a tape loop. By this technique, a detailed frequency analysis can be obtained even on a short sample of a given noise.

Since a signal or an event can be recorded at one tape speed and played back at a different speed, signals can be analyzed with instruments that do not have the frequency range of the signal being recorded. This is accomplished by increasing the frequency of low frequency signals by recording at a slow speed and playing back at a higher speed and by doing the opposite for a high frequency signal. The frequency transformation is directly proportional to the change in tape speed. Tape recorders also allow for the simultaneous collection of data from many measurement locations, such as a site survey of noise near an airport.

Thus far, no discussion has been made of the readout devices available. The choice depends mainly on the type of noise to be analyzed but may include meters, oscilloscopes, graphic level recorders, and computers.

Meters are typically useful for steady noise and usually provide the average, peak, or root-mean-square (rms) value of the electrical signals. The peak value for intermittent or impulsive noises can be read utilizing peak-hold meters. Such devices hold the level of the peak (either the electrical peak or the peak rms level) but provide no information on the duration or waveform of the impulse. If impulsive sounds are measured on a storage oscilloscope, then not only the peak noise levels can be determined but also the duration and the manner in which the noise decays. Another practical readout device is the graphic level recorder. This device is essentially a recording voltmeter that, when used synchronously with a set of filters, provides a permanent strip chart record of sound levels in various filter bands. The response of the graphic level recorder may not be fast enough for use in analyzing impulsive sounds; however, it is useful for analyzing intermittent sounds such as aircraft flyovers.

When a large amount of data must be analyzed, a digital computer becomes almost a necessity. For example, assume that automobile passby noise of approximately a 5-second duration is available for analysis. If the frequency range of interest is 100 to 10,000 Hz (21 one-third octave bands between 100 and 10,000 Hz) and a frequency spectrum is desired every 0.5 second, there would be approximately 210 pieces of information (21 one-third octave bands times 10 interrogations during the duration of the passby) for every passby. If many automobiles were tested at various speeds, loads, pavement surfaces, etc., the amount of data points would number in the millions. Such a measurement and analysis program would require a computer to efficiently handle the data.

The selection of instrumentation for measuring and analyzing sound is not always a simple task. The following basic considerations are suggested so that an appropriate choice can be made:

1. Consider the type of sound (noise) to be measured.

   (a) Steady wideband noise - air moving through ducts
   (b) Steady narrow band noise - circular saw
   (c) Impulse noise - gunfire
   (d) Repeated impulsive noise - riveting
   (e) Intermittent noise - aircraft flyover

2. Consider the information desired from the analysis. For determining potential damage to hearing, interference with speech communication, or annoyance, octave band analysis may be sufficient if there are not significant pure tones in the noise. However, if the intent is to obtain data for the redesign of a noisy component such as a gear train, narrowband analysis may be necessary.

3. Consider the time available. This is essentially an operating and economic question. If one wants to measure rocket noise, the time available for recording the sound is extremely limited; and if the instrumentation system is not designed properly to record the sound, there will be no chance to repeat the test. For analysis of steady-state noise, the shortest test should be devised to obtain the information desired. Any further data or analysis would be costly and would be a wasted effort since it would provide no additional information.

Since all acoustic equipment has its basic limitations, the above considerations , plus the effect of the environment (temperature, wind velocity, humidity, etc.) on the instrumentation, must be evaluated so that an appropriate instrumentation system may be selected for the specific noise measuring task. In general, the standard requirements for acoustical instrumentation are clearly indicated so that acousticians know the accuracy and precision of their equipment. Calibration devices are available, and calibration techniques are well established. In general, existing instrumentation is available and is adequate for use by experienced acousticians in addressing noise problems. There is a need for rugged, reliable special purpose instrumentation (e.g., noise exposure meters) that can be used by inexperienced personnel without a need for extensive training in operation and calibration procedures.

There are a great many noise sources and noise environments to which people are exposed. The noise level produced by a given machine in a specific location is dependent not only on the sound radiating characteristics of the machine itself but also upon the type of mounting, the manner in which the machine is operated, and the environment in which it is placed. For these reasons, it is generally preferable for measurements to be made under acoustically well-defined conditions.

Basically, there are two different acoustical environments that may be used--the free field and diffuse field. The acoustically free field--a field without any sound reflecting obstacles--is not always possible to obtain in practice. Nearly ideal free field conditions can be obtained in anechoic chambers (rooms in which the boundaries absorb effectively all the incident sound). However, some devices are too heavy to be suspended in the center of an anechoic chamber, while others are too large to fit in the available chamber. A simple acoustical environment that closely approximates actual operating conditions for many types of noise sources is that obtained by mounting the source on a smooth hard reflecting plane with no disturbing sound-reflecting objects nearby. Flat open outdoor areas free of large reflecting surfaces, such as buildings, or trees typically provide such an environment.

A noise source in an anechoic space or an anechoic half space (e.g., over a reflecting plane) can be characterized by measuring the sound pressure level at various points surrounding the source. If the measurement points are selected so that they lie on a spherical surface (or on a hemisphere) around the source (the radius of the sphere should be large enough to ensure farfield* conditions), it is possible to calculate the total sound power radiated by the noise source as well as its directivity.

The second type of well-defined acoustical environment is the diffuse sound field. By placing a sound source in a large reverberant chamber--a room with sound-reflecting surfaces--it is possible to create a sound field in which the time-averaged flow of sound power is the same in all directions. It is then possible to calculate the sound power level by measuring the volume of the room, the reverberation time (a measure of the absorption of the room boundaries), and the sound pressure--which in an ideally diffuse sound field can be obtained from a single measurement. It should be evident that in this case it is impossible to determine the directivity of acoustical radiation from the noise source.

It is useful to describe four terms relating to noise control in buildings--absorption coefficient, reverberation time, noise reduction, and sound transmission loss. Acoustical materials are usually described (for the purpose of noise control) as those that have the property to absorb a substantial amount of the energy of sound waves striking their surface. The sound absorption coefficient of any material represents the ratio of the sound energy absorbed by the surface to the sound energy incident upon the surface. The absorption coefficient may vary from nearly 0 percent (perfect reflector) to nearly 100 percent (perfect absorber). The absorption coefficient depends on the nature of the material itself, the frequency of the sound, and the angle at which the sound waves strike the surface. The two principal requirements to ensure efficient absorption are:

1. The exposure of a large amount of surface area to the sound.
2. The movement of air within the volume occupied by the material.

In addition, even though a material is porous and exposes a large amount of surface area, it may not be an efficient absorber. This is the case when absorbing material, e.g., acoustical tile, is attached directly to a massive wall. As sound strikes the wall, it is almost totally reflected due to the large difference between the speed of sound in the wall material as compared with the speed of sound in air. If the same material was spaced away from the wall, the absorption would be much greater.

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*for a definition of "farfield", see Appendix A, Glossary.

To determine the total sound absorption of a room, the reverberation time of the room is measured. Technically, the reverberation time of a room is the time required for any sound to decrease in amplitude by 60 dB if the sound is turned off and allowed to decay. If the absorption within the room is great, the reverberation time is short; however, if the room is acoustically live (has little absorption), the reverberation time is longer. As a source generates noise in an enclosure, part of the noise is absorbed and, eventually, a condition exists in which the sound power radiated is equal to the sound power absorbed--at which point the steady state value of the sound pressure is reached within the room. Therefore, the greater the sound absorption within a room, the lower the average steady state sound pressure will be.

A frequent problem in noise control is the provision of partitions or enclosures designed to reduce the sound transmission from one space to another. The acoustical privacy may be expressed in terms of noise reduction, which by definition is the difference in noise levels produced between two dwelling spaces by one or more sound sources in one of the spaces. Occasionally the noise reduction between specific locations in the spaces is desired. However, usually the difference between the space-time average sound pressure levels, as a function of sound frequency, is measured or specified. Note that the concept of noise reduction does not include any assumption as to the path along which the sound is transmitted between the two spaces.

The sound transmission loss of a partition, in a specified frequency band, is the ratio, expressed in decibels, of the airborne sound power incident on the partition to the sound power transmitted by the partition and radiated on the other side. That is, it is a measure of the sound insulating capability of the wall itself, based on the assumption that the wall represents the only path through which the sound may be transmitted.

3. Measurement of Effects of Noise on Man

This section broadly sketches methods that have been used to measure the effects of noise on man.

An important physiological effect of excessive noise, and therefore the basis for an important noise criterion, is permanent hearing handicap. This might occur after a person has been exposed to loud sounds on a recurrent daily basis over a long period of time. Occupational deafness represents this type of problem, as noted in surveys of workers in heavy industry. The measurement of hearing loss of a person is accomplished by measurement of the lowest (weakest) sound pressure level, called the threshold, that the individual can hear. This is done with an audiometer, which is an electroacoustical instrument consisting of an electronic oscillator, attenuator, and earphone for producing sound pressure levels in the ear of the subject at various frequencies. The amount, expressed in decibels, by which a person's measured threshold of audibility exceeds the standard (normal) audiometric threshold is his hearing threshold level. Hearing measurements made with audiometers are thus expressed as hearing threshold levels (in dB) at various pure-tone frequencies (in Hz). A person is recognized as having a slight hearing impairment for speech sounds whenever the average of his hearing threshold levels at 500, 1000, and 2000 Hz lies between 25 and 40 dB.

Hearing impairment has been studied from the standpoint of anatomical structure as well as function. Researchers, both in and outside the medical profession, have built up a substantial body of information based on histological findings and neurophysiological measures in animals as well as humans. A great deal is now understood about the permanent damage to the hair cells of the cochlea caused by intense noise that has certain specified characteristics.

Another measurement, more complex than pure-tone audiometry and commonly used to assess hearing damage, employs meaningful material as stimuli. Standardized words, phrases, and sentences are presented to the subject under controlled conditions, and intelligibility scores are obtained based on the percentage of material accurately identified.

Other general types of measures, usually associated with "non-auditory effects of noise," should really be termed indicators or measures of stress. They consist of physiological and chemical measures associated with the functioning of the body as a whole. Under this general category fall EEG, EKG, blood pressure readings, urine analyses, etc.

Intelligibility-of-speech measurements are also used in studies concerned with the masking effect of noise. Since verbal communication plays a major part in many activities, such tests have widespread application. The test content depends primarily on the function for which the test is designed. For example, for general applications, the words should be representative of the English language in that each phonetic sound included in the test should be represented on the basis of its frequency of occurrence in the language. Therefore, "s" would appear much more frequently than "x" in the pool of words or sentences used in the test.

The articulation test is a standardized procedure for determining the probability of reception of a message under adverse conditions of communication. In such tests, speech communication is simply represented as a series of message units (test items) selected according to certain rules from a set of such units. These message units are spoken in a well-defined sequence by a speaker to a listener, and the listener records his response after the presentation of each test item (in laboratory tests, tape recordings often are used). If the message set is not specifically known to the listener, it is termed an open set. Another approach is the use of a closed message set, in which the listener knows the message so well that the responses are restricted to those narrowly defined experimentally as being appropriate. The task for the subject is, therefore, a different one. The closed message set is often used when a highly communicative system employing a selected vocabulary is being evaluated, e.g., ground-to-air communications.

Measures of performance degradation in the presence of noise are typically based upon laboratory investigations as well as field studies. Usually, one experimental group performs a task in the presence of noise and another group having similar characteristics performs the same task under quiet conditions. The performance of each group is then examined to determine whether there is any decrement in performance, and if so, whether it can be attributable to the presence of noise.

Another laboratory measure often used has depended upon a number of psychophysical techniques to rate the annoyance (or relative acceptability) of sounds. In some instances, sounds are presented in pairs and relative judgments are required, while other techniques have been based upon absolute judgments and scaled comparisons. The methodology differs depending on the type of data desired. In paired comparisons, the judgment is a relatively easy one -- which one of the two sounds presented is more (or less) acceptable? The absolute measure is often used when a decision point is required -- at what point is the noise unacceptable? The scaled judgment is the most difficult and refined technique in that subjects are not only asked to indicate whether one sound is louder than another but also to put it into quantitative terms by indicating how much louder.

A variety of methods has been used in field research. The most commonly used technique has been primarily based on questionnaires administered during community surveys. The typical approach is to ask questions about the environment and the acceptability of an area for residential purposes rather than to directly ask questions about noise problems. The latter approach has led to biased data. The types of questions are often directed at identifying noise sources and to ranking these with respect to annoyance or scaling responses, for example from 1 to 5 on the degree of annoyance. General attitudinal measures toward the immediate environment as well as personal background information are often taken in conjunction with noise measures to control against possible biases such as general disaffection (as opposed to specific problem identification).

Other measures of the effects of noise that do not result from systematic and controlled studies are also available. Complaints due to noise and the formation of community organizations to combat the effects of noise are obvious indicators. Economic and social data based on resale value of homes and reasons given for moving from certain locations have also been employed as indicators relating to the problem.

Lastly, a number of researchers has actually moved their controlled laboratory research into the field to better simulate real world conditions. Annoyance and sleep interference data have been collected using this combination of laboratory-field research technique.

4. Correlations between Noise and Human Response

In the preceding material, the discussion concerned (a) measurement of the physical attributes of noise, and (b) measurement of the effects of noise on persons. In the present section, the discussion concerns correlations between the physical attributes of noise and the resultant effects on humans. Attention is centered on the suitability and effectiveness of various noise exposure rating schemes used to estimate or predict the effects of noise on man.

This section is divided under headings corresponding to the particular effect being considered: hearing damage, communication interference, and disturbance due to noise. Physiological damage, other than that to the hearing mechanism, is not discussed since the nature of any possible chronic extra-auditory physiological effects has not been sufficiently well defined to permit establishment of quantitative causal relations. Under each heading is a brief description of the relevant parameters involved and appropriate literature references.

4.1 Hearing Damage

Excessive noise exposure causes a loss of hearing acuity. A temporary hearing loss, or temporary threshold shift (TTS), can result from short-term exposure to high-level noise. A permanent threshold shift (PTS), can result from either continued exposure to high-level noise or short exposure to very high level noise. The permanent hearing damage risk associated with noise depends upon (1) the intensity and frequency distribution of the noise, (2) the duration of each individual exposure, (3) the number of individual exposures per day, (4) the number of years over which the daily exposure is repeated, and the individual susceptibility to this type of damage. Since significant noise-induced PTS may take years to develop and because the detailed noise exposure history over those years may be very difficult to document, the establishment of valid correlations between noise exposure and PTS has presented serious difficulties. In the case of occupational exposure to extremely high levels of noise - - far in excess of those routinely encountered away from the workplace - - the associated occurrence and degree of hearing damage can be established with considerable confidence. However, at lower levels of exposure, demonstration of causal relationships is difficult. In order to assist in predicting the permanent hearing damage risk associated with a given noise exposure, two theories have been advanced.

The first of these - - the equal energy theory - - hypothesizes that permanent damage to the hearing mechanism is related to the total noise energy to which the ear is exposed. The operational simplicity of this theory makes it quite attractive; however, there has been little direct experimental verification and some authorities are very dubious - - particularly since this theory does not permit consideration of the time distribution of the noise exposure.

The second theory - - the equal temporary effect theory - - hypothesizes that permanent damage to the hearing mechanism, due to a given (daily) noise exposure, is related to the temporary threshold shift produced by the same noise exposure. In other words, noise exposures which produce the same TTS will produce the same ultimate PTS. This theory is supported by data showing that those noise exposures that ultimately produce PTS also produce TTS in "young normal ears". Conversely, those noise exposures that do not produce PTS likewise do not produce TTS in "young normal ears". However, in this instance also there has been little direct experimental verification of a relationship between the temporary and permanent hearing losses that a given noise exposure produces.

Current guidelines for occupational noise exposure control are primarily aimed at protecting hearing in a restricted range of frequencies, typically 500 to 2000 Hz, which is critical to the understanding of speech. On this basis hearing handicap is defined as: the condition wherein the average hearing threshold levels at 500, 1000, and 2000 Hz exceed 25 dB. This definition is used in conjunction with the hearing conservation guidelines issued in 1970 by an Intersociety Committee (representing the American Academy of Occupational Medicine, the American Academy of Ophthalmology and Otolaryngology, the American Conference of Governmental Industrial Hygienists, the Industrial Hygiene Association, and the Industrial Medical Association)[1].* These guidelines, with which present Federal regulations are consistent, are intended to protect 80 to 90 percent of the exposed worker populace from noise-induced hearing handicap, as defined above. Empirical data have been used as the basis for establishing guidelines for group exposure to continuous noise. The recommendations for limits on intermittent, or interrupted, exposure are based mainly on studies of temporary threshold shift resulting from various types of noise exposure.

The above-referenced guidelines, which are directed toward the prevention of permanent hearing loss resulting from exposure to steady noise, whether continuous or intermittent, specify that either the A-weighted sound level or the octave-band sound pressure levels may be measured. However, an "equivalent A-weighted sound level", determined from the octave band levels with the use of Figure 6, is preferable to a direct A-scale reading if the latter is within 3 or 4 decibels of the selected critical level for noise control. Once the equivalent A-weighted sound level is determined, the maximum recommended exposure time is obtained from Table 1.

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*Figures in brackets indicate the literature references given at the end of this section.

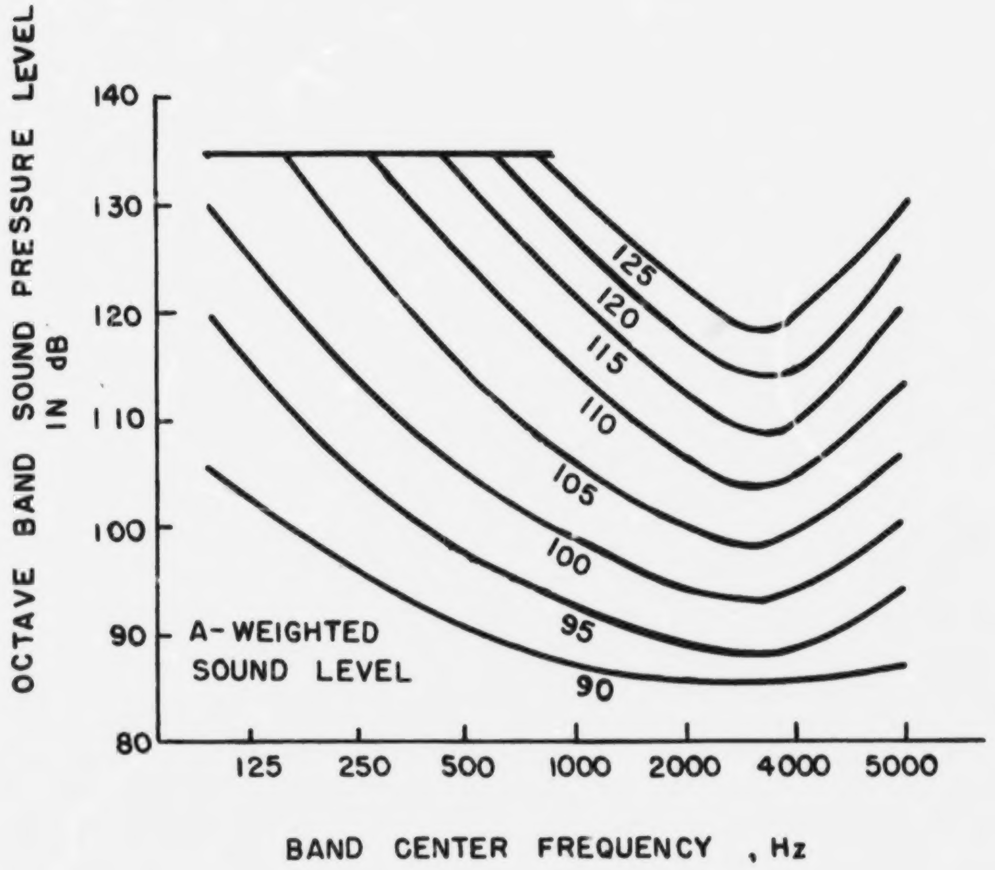

Figure 6. Equivalent sound level contours. Octave band pressure levels may be converted to the equivalent A-weighted sound level by plotting them on this graph and noting the A-weighted sound level corresponding to the point of highest penetration into the sound level contours. This equivalent A-weighted sound level, which may differ from the actual A-weighted sound level of the noise, is used to determine exposure limits promulgated under the authority of the Occupational Safety and Health Act of 1970.

Table 1

Maximum Recommended Occupational Noise Exposure

The values in parentheses are not explicity given in the guidelines [1] being discussed but are consistent therewith and are given explicitly in present Federal regulations [2].

Sound Level dBA	Daily Exposure Time hr
90	8
(92)	(6)
95	4
(97)	(3)
100	2
(102)	(1-1/2)
105	1
110	1/2
115	1/4 or less

This table is based upon: (1) data which indicate that an 8 hour per day continuous exposure to levels below 90 dBA, over a period of many years, will not produce a noise-induced hearing handicap, as defined above, in 80 to 90 percent of the exposed population, and (2) data, mainly from studies based on temporary threshold shifts, which indicate that for each halving of the time of noise exposure per day the noise level may be increased by 5 dB without increasing the hazard of hearing impairment.

These guidelines specify that when the daily noise exposure is composed of two or more periods of noise exposure of different levels, their combined effect should be considered, rather than the individual effect of each. If the sum of the following fractions:

$$\frac{C1}{T1} + \frac{C2}{T2} + \; . \; . \; . \; \frac{Cn}{Tn}$$

exceeds unity, then the mixed exposure should be considered to exceed the threshold limit value. C1 indicates the total time of exposure at a specified noise level, and T1 indicates the total time of exposure permitted at that level. Noise exposures to sound levels of less than 90 dBA do not enter into the above calculation.

The permissible limits (guidelines) given in Table 1 are primarily concerned with occupational noise exposure. Such limits are typically keyed to a maximal eight-hour exposure day and, further, assume quiet conditions to exist outside of the usual eight-hour work period to permit auditory recovery. Occupational noise exposure limits are primarily aimed at protecting most, but not all, of the worker population from suffering a hearing impairment resulting in a handicap for understanding speech. The protection provided by such limits may be viewed as acceptable in an industrial setting since the worker can be financially compensated for any hearing damage incurred. However, in off-job situations it would appear justifiable to strive to protect all persons from any measurable loss of hearing due to noise exposure. This would include protection of hearing at higher frequencies which are very important, for example, to the appreciation of music.

A recent paper [3] by Cohen, Anticaglia, and Jones of the National Noise Study, U. S. Department of Health, Education, and Welfare, suggests the noise limits given in Table 2 for non-occupational noise exposure. These were set 15 decibels below the occupational limits (Table 1) in order to provide protection of essentially all persons at all audiometric frequencies. These suggested limits appear reasonable but there is a need for supportive data regarding both continuous and intermittent noise.

Table 2

Maximum Suggested Non-Occupational Exposure

Sound Level dBA	Daily Exposure Time
70	16-24 hour
75	8
80	4
85	2
90	1
95	30 minutes
100	15
105	8
110	4
115	2

Guidelines have also been prepared to estimate the hearing damage risk associated with impulse noise, such as gunfire. Impulse noises, for this purpose, can be defined as brief noises lasting less than 1 second.

The available data on hearing damage due to impulse noises are mainly derived from studies of military personnel. In general these data do not provide reliable indications of the actual noise exposures which caused the measured hearing loss. The guidelines discussed below are based primarily on results of temporary threshold shift (TTS) studies. Since there are essentially no data directly relating TTS from a single noise exposure to the noise-induced permanent threshold shift from habitual exposure, these recommendations should be used with some caution. However, they do represent the best information available to date.

In general, a noise can be considered dangerous to hearing if the temporary threshold shift (TTS) measured two minutes after the exposure regularly exceeds 10 dB at or below 1000 Hz, 15 dB at 2000 Hz, or 20 dB at or above 3000 Hz. Moreover, immediate permanent damage may occur whenever the TTS produced by a single exposure exceeds 40 dB. A permanent threshold shift (PTS) may also occur if a TTS has not disappeared within 24 hours.

Impulse noises are broken down into two general types [4,5], illustrated in Figure 7, although intermediate forms do occur. Figure 7(a) shows the pressure waveform that is often observed when a gun is fired outdoors with no reflecting surfaces nearby. Figure 7(b) exemplifies a much more complicated situation: an initial series of damped oscillations which may be followed by a reflected wave at only a slightly lower level. There are three parameters of a single impulse noise which are of importance to the criterion being discussed:

(1) The peak pressure level (P) is the highest instantaneous pressure level (expressed in decibels re 20 $\mu N/m^2$) reached at any time by the impulse, measured at the position of the ear with the individual not present.

(2) The pressure-wave duration, or A-duration, is the time for the initial or principal pressure wave to rise to its positive peak and return momentarily to ambient pressure. In the ideal pressure wave shown in Figure 7(a), the A-duration is given by the distance (W-V) on the time axis.

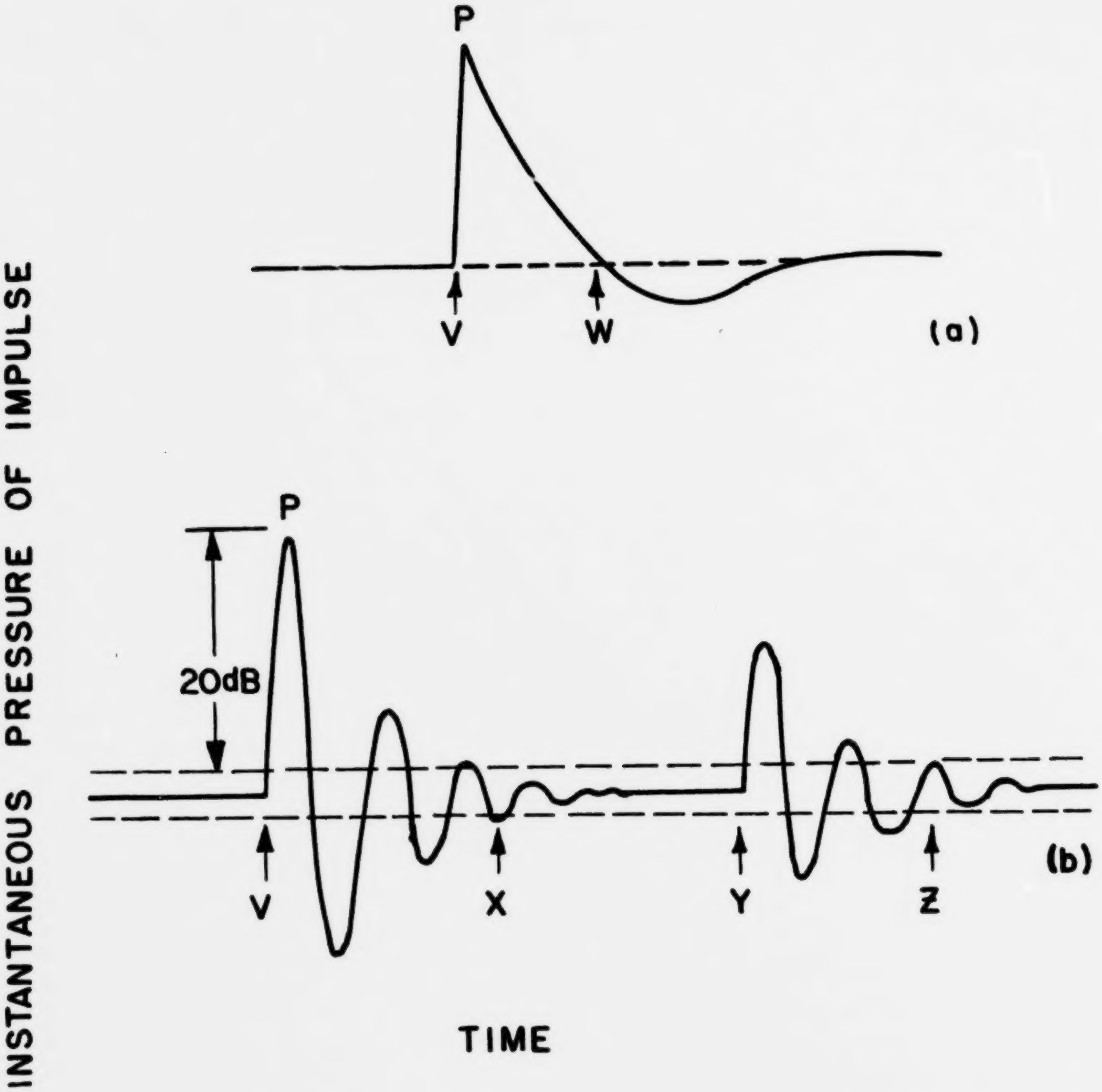
INSTANTANEOUS PRESSURE OF IMPULSE
P
V
W
(a)
P
20dB
V
X
Y
Z
(b)
TIME

Figure 7. Two principal types of impulse noise. A-duration is the time required for the initial or principal pressure wave to rise to its positive peak and return momentarily to ambient pressure. The pressure-envelope duration, termed B-duration, is the total time that the envelope of the pressure fluctuations, both positive and negative, is within 20 dB of the peak pressure level.

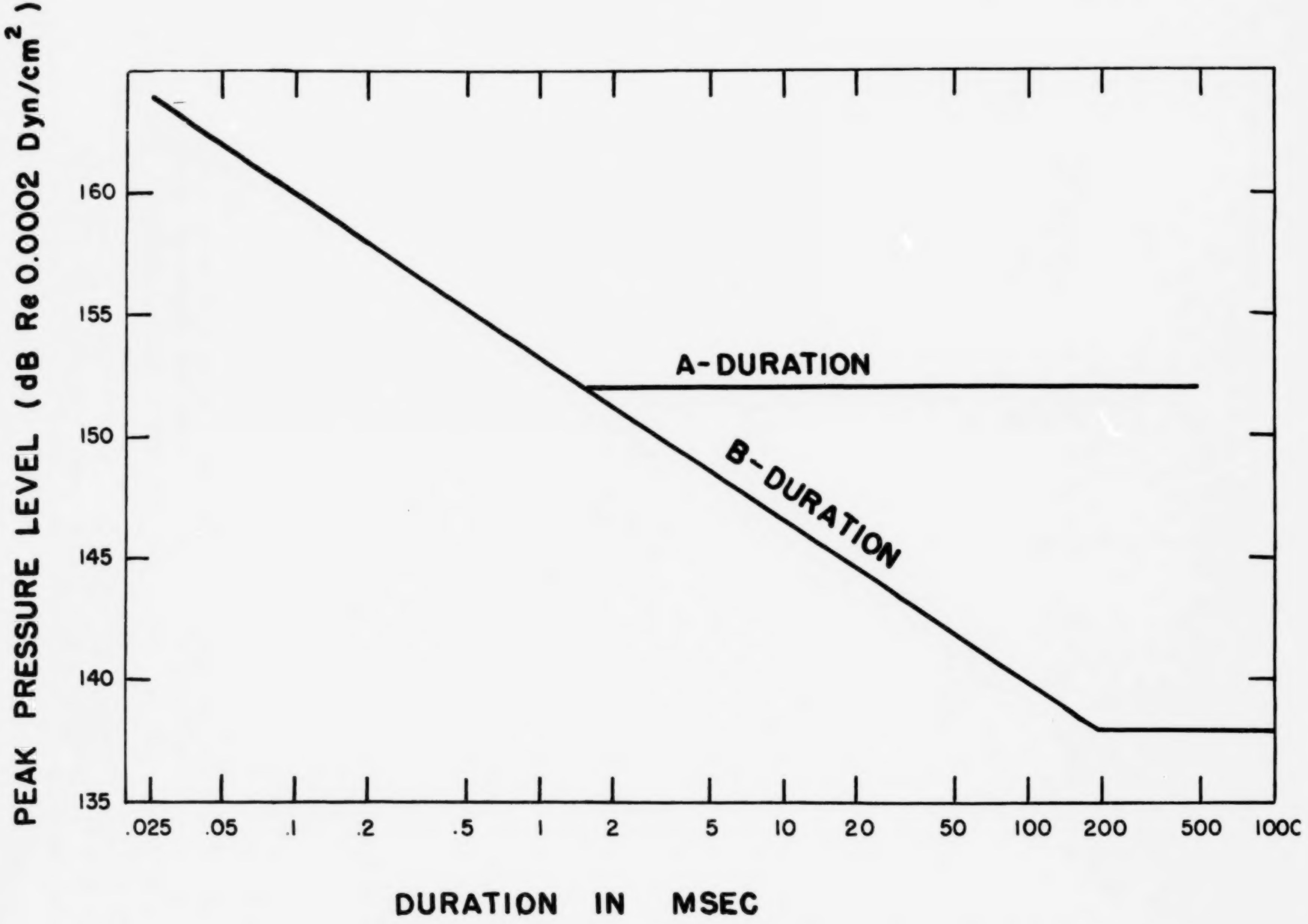

Figure 8. Damage-risk criterion for impulse noise. The acceptable peak-pressure exposure limits are based on sound waves impinging on the ear at normal incidence as a function of either A or B pulse duration. The criterion is based on the assumption of 100 exposures per day.

(3) The pressure-envelope duration, or B-duration, is the total time that the envelope of the pressure fluctuations, both positive and negative, is within 20 dB of the peak pressure level. Included in this time is the duration of that part of any reflection pattern that is within 20 dB of the peak level. Thus in Figure 7(b), the B-duration is given by (x-v) + (z-y).

Figure 8 presents the fundamental criterion developed by the CHABA working group [5]. This criterion is intended to limit the temporary threshold shift, measured two minutes after cessation of exposure to the noise, produced in all but the most susceptible five percent of exposed individuals, to less than 10 dB at 1000 Hz and below, 15 dB at 2000 Hz, or 20 dB at 3000 Hz or above. The criterion is based on the assumption that the permanent hearing loss (noise-induced permanent threshold shift) eventually produced by many years of exposure to noise is approximately equal to the temporary threshold shift shown by a normal ear after a single day's exposure to the same noise. The criterion shown in Figure 8 represents the limits for 100 impulses distributed over a period of four minutes to several hours on any single day. It is assumed that the pulses reach the ear at normal incidence. In case of doubt as to which waveform analysis to apply, the more conservative B-duration should be used. The main features of the criterion are as follows:

(1) The maximum peak pressure level permitted, without ear protection, is 164 dB for the shortest pulse of any practical interest (25 microseconds).

(2) As duration increases, the permitted peak pressure level decreases steadily at a rate of 2 dB for each doubling of the duration, dropping to a terminal level of 138 dB for B-durations of 200 to 1000 milliseconds.

(3) A similar decrease occurs for A-durations, except that a terminal level of 152 dB is reached at about 1.5 milliseconds.

In case the conditions stipulated for this basic criterion are not met, correction factors can be applied as follows:

(1) If the pulses arrive at the ear at grazing incidence instead of at normal incidence, the curves can be shifted upward at 5 dB (that is, 5 dB can be added to the ordinate values in Figure 8).

(2) If the number of pulses in an "exposure period" (that is, on any given day) is some value other than 100, the following corrections should be added to the permissible peak pressure level of the impulse:

Number of impulses per day	Correction dB
1	+15
10	+11
20	+10
50	+ 5
100	0
200	- 5
300	-10
500	-15
1000	-20
2000	-25
5000	-30

These corrections are taken from the more recent work of Coles and Rice [6] rather than from the original CHABA report [5].

For more detailed discussions of hearing damage risk from exposure to noise and proposed procedures for estimating hearing damage risk, as well as an extensive bibliography, the reader is referred to the recent book by Kryter [7].

4.2 Communication Interference

One of the most directly observable effects of noise is its interference with communication. Considerable research has been carried out on the extent to which a tone or a band of noise will "mask" other tones or bands of noise. The methodology of such experiments usually is to determine the audibility threshold at each frequency of interest with and without the masking noise present. In general, the following observations can be made: (a) the range of frequencies affected increases with the intensity of the masking tone; (b) the magnitude of masking varies in the main, with the nearness in frequency of test and masking sounds; (c) tones higher in frequency than the masking tone are affected more than tones lower in frequency; (d) the lower the frequency of the masking sound, the more widely spread is its effect; and (e) sufficiently intense levels of high frequency noise will cause remote masking in which low frequency sounds are masked. While there do not appear to be existing standards for predicting audibility thresholds in the presence of masking sounds, the field appears to be reasonably well researched and such prediction could probably be effected if needed. However, in many situations the degree to which a noise affects "audibility" is less important than the degree to which noise affects the "noticeability" or "conspicuity" of a signal. As an example, a warning siren in the presence of noise might be audible in a controlled laboratory situation but might rarely be noticed in a real situation wherein one was not intensely concentrating on detecting the siren. There is a need to develop techniques for predicting the extent to which noise prevents warning signals from being noticed.

Considerable work has been done on measures for estimating the extent to which noise will interfere with speech communication. The most accurate index is the Articulation Index--calculated according to the procedures of American National Standard S3.5-1969--which is an estimate of the proportion of the normal speech signal that is available to a listener for conveying speech intelligibility in the presence of noise. The basic calculation of the Articulation Index is based upon the signal-to-noise ratio in each of 20 frequency bands, covering the range 200 to 6100 Hz, which are selected so that in the absence of noise the speech components within each band contribute equally to speech intelligibility. (Although the Articulation Index is based on equal contribution of each of 20 frequency bands to speech intelligibility, empirical verification is still very sketchy.) Alternatively, the Articulation Index can be computed from 1/3-octave or full octave band sound pressure levels with weighting factors being used to account for the relative contribution of each band to speech intelligibility. The octave-band method of calculation is not as precise as the 20-band or the 1/3-octave band method.

The Articulation Index is based upon, and has been principally validated against, intelligibility tests involving adult male talkers and trained listeners. It adequately predicts speech intelligibility in the presence of steady-state noise and contains provisions for predicting the effect of noise having a definite off-on cycle. It does not purport to predict the intelligibility of speech in the presence of fluctuating noise levels. The method cannot be assumed to apply to situations involving female talkers or children. It must therefore be used with caution in estimating speech interference in ordinary home and work situations. Finally, the complexity of the calculation procedure required to obtain the Articulation Index limits its usefulness in the measurement and monitoring of noise levels on a routine basis.

The Speech Interference Level (SIL), which is being proposed as an American National Standard, is a simple numerical method for estimating the speech-interfering aspects of noise based on physical measurements of the noise. Unlike the Articulation Index, SIL does not include specific consideration of the level and spectrum of the speech but employs a table or a monograph for estimating the noise levels which will seriously restrict speech communication in terms of general voice level and distance between communicators. SIL is defined simply as the arithmetic average of the sound pressure levels in the three octave bands centered on the frequencies 500, 1000, and 2000 Hz, respectively.

For steady-state noises, the SIL is a reasonably accurate predictor of the relative ranking of noises with respect to their speech-interfering properties. That is, two noises which are equally-interfering with speech communication will have very similar SIL ratings (typically within 5 dB; if more precision is needed, the Articulation Index should be used). With somewhat greater uncertainty, SIL can be used for rough, quantitative estimation of monosyllabic word intelligibility in the presence of continuous, random noise. However this procedure is not appropriate for noise spectra with considerably more energy at high frequencies than at low or when any of the following conditions exist: (1) the noise is not of a continuous-in-time, steady-state nature; (2) the frequency spectrum of the noise is not continuous; and (3) the speech and noise are subject to perceptible echo or reverberation.

The monograph shown in Figure 9 can be used for rough estimates of the voice level and distance between talker and listener for satisfactory face-to-face speech communication as limited by ambient noise levels having the SIL values shown. Here again the noise is assumed to be steady-state. The second abscissa, in dBA, reflects the correlation between SIL and A-weighted sound level for many types of noise. Similar correlations have been shown, for example, between SIL and loudness level (LL) and between SIL and perceived noise level (PNL)--LL and PNL will be described below. Since spectral data are needed to compute both loudness levels and perceived noise levels, there is no reason to use these measures in place of SIL, which is simpler to compute and is a better predictor of speech interference. Because the A-weighted sound level can be read directly from a sound level meter, it is an easier measure to obtain than SIL. However, if significant high frequency energy is present, some caution should be exercised since sound level meter measurements tend to overrate the speech-interference properties of high-frequency noise.

While AI and SIL can be extremely useful, there is a need to develop predictive techniques for speech interference with male and female speakers, both adult and child, and untrained listeners in a real, rather than a laboratory, situation. Consideration should also be given to the additional problem of listeners suffering from impaired hearing. Statistical predictors need also to be made available which take into consideration the speech-interference aspect of rapidly varying and fluctuating noises such as those produced by heavy traffic.

4.3 Disturbance Due to Noise

Perhaps the most prevalent, most researched and still least understood behavioral effect of noise is its "disturbing" or "annoying" quality. Since even these descriptive terms are highly subjective, it has been extremely difficult to develop an adequate general methodology which relates in quantitative terms the physical characteristics of sounds with the psychological responses to them. The history of research in this area does have one common theme: the assumption that the primary variable linking physical and psychological measures is the intensity of the sound. The progression of research interests

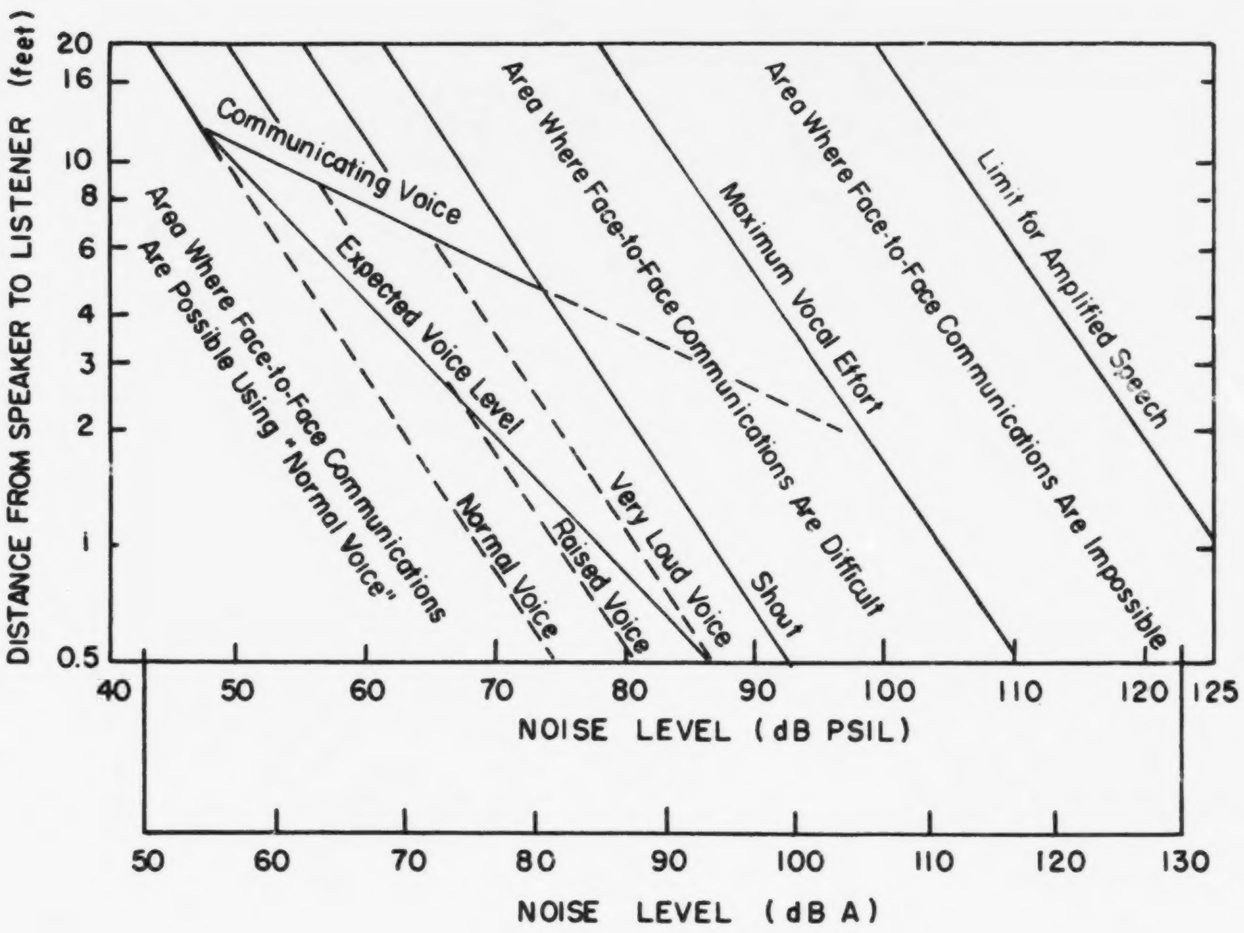

Figure 9. Voice level and distance between talker and listener for satisfactory face-to-face speech communication. An example for interpreting this chart: Jet aircraft cabin noise is roughly 80 ±2 dBA. At 80 dBA in their expected (raised) voice level, seat mates can converse at 2 feet and, by moving a little, can lower their voices to normal level and converse at one foot. To ask the stewardess for an extra cup of coffee from the window seat (4 feet), one would need to use his very loud communicating voice.

over the years reflects this priority. While early studies were largely limited to relating loudness (the intensive attribute of an auditory sensation) with physical descriptions of sounds, in recent years investigators have started with loudness as a base to be corrected by means of other relevant variables (time, pure tone components, etc.). Another characteristic common to these psychoacoustic studies is the use of "equal loudness contours" as a basic measurement method. These are families of curves showing the sound pressure levels at which pure tones, or bands of noise, are judged equal in loudness to a 1000 Hz reference tone or band of noise set at a fixed sound pressure level. Equal loudness contours have been developed by a number of investigators using slightly different procedures; these variations in methodology in some instances have produced conflicting findings.

The earliest attempts to quantify the subjective magnitude of sounds were made at the Bell Laboratories by Fletcher and Munson. These studies were designed to define and measure loudness. Their basic rationale was that loudness was proportional to the number of impulses leaving the cochlea upon stimulation. They also hypothesized that two tones competing at a single nerve fiber would interfere with simple loudness summation and that it must be necessary to group together all components within a certain frequency band and treat them as a single component. The width of the bands grouped together was estimated to be 100 Hz for frequencies below 2000 Hz, 200 Hz for frequencies between 2000 and 4000 Hz and 400 Hz for frequencies between 4000 and 8000 Hz.

Loudness level was defined by Fletcher and Munson as the intensity level of a tone when compared with a reference tone having the single frequency of 1000 Hz. The procedure employed in data collection is known in psychophysics as the "method of average error". The experimental subjects adjust the intensity level of a reference tone until it is judged as being equally as loud as the standard. A compilation of many judgments, by a sample of subjects making these judgments with a variety of tones varying in intensity levels, results in data that can be presented in the form of equal loudness contours such as shown in Figure 10.

The Fletcher and Munson contours are seldom used in their original form today, because of a number of difficulties, although the basic rationale and methodology have been adopted by most later researchers. The data collection technique has proven to be a very laborious, costly and time consuming one. In addition it was found that the procedure was deficient in its application to "unsteady complex sounds".

A major advance in methodology was introduced by S. S. Stevens who, while retaining the concept of equal loudness contours, developed a new methodology in defining them. Instead of confining judgments to those of equality, he had subjects make estimates in terms of magnitude estimation. His basic procedure was as follows: A standard tone of 1000 Hz at 40 dB is given the arbitrary value of 1 sone in the development of the scale. Subjects make adjustments of a comparison sound, for example, until it is twice as loud as the standard; this level is defined as 2 sones. Judgments are then made as to half the loudness of the standard; these are defined as 1/2 sone. Further comparisons can then be made in a similar manner for 1/4 sone and 4 sones, etc. Intermediate points are then computed on the basis of bisection between the empirically based data. Later work by Stevens, Beranek Robinson, Zwicker and others using the same general methodology and sone scale have been based on 1/3-octave and octave noise bands rather than pure tones. It was assumed for these purposes that an octave band of random noise having the same overall sound pressure level as a pure tone of the same center frequency would be equally loud. Stevens, in a later modification of his procedure, demonstrated that his method was more accurate in predicting the judged loudness of complex sounds consisting of bands of random noise than the method of simply adding together the sone values of individual bands.

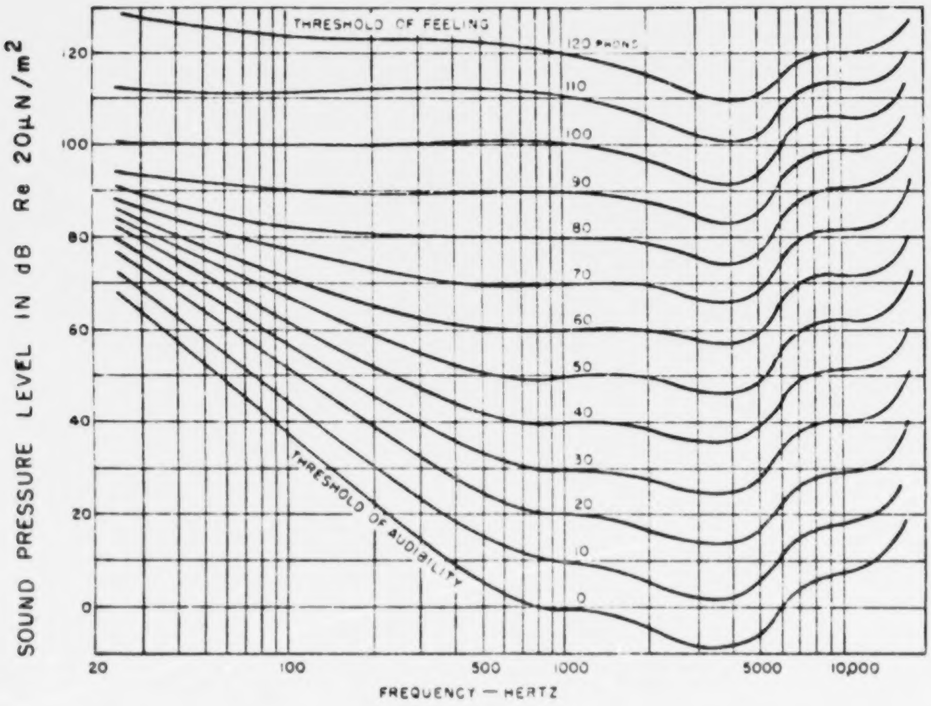

Figure 10. Equal loudness level contours (Fletcher-Munson curves).

Steven's general formula is to add to the sone value of the loudest band a fractional portion of the sum of the sone values of the remainder of the bands:

$$\text{Loudness} = Sm + f\ (\Sigma S - Sm)$$

where ΣS = sones in all bands, S_m = maximum number of sones in any one band, and f = fractional portion dependent on bandwidth. Stevens derived the fractional portion to be applied when the spectrum of the sound was measured in either full (f = 0.3), one-half (f = 0.2) or one-third (f = 0.15) octave bands.

Another method of computation was developed by Robinson who conducted a series of investigations to determine equal loudness contours in a diffuse sound field (minimal audible field-MAF measures) based on pure tone data (Figure 11). He and his colleagues used a psychophysical technique different from that used by Fletcher and Munson. Instead of having subjects adjust the level of the standard sound themselves (method of average error), they are presented with predetermined pairs of sounds. One pair member is the standard and the other, the comparison tone. The task of the subject is to judge which sound is loudest. The level of the comparison sound is varied systematically from much more intense to much less intense than the standard. The order of presentation of the standard and comparison tones are carefully controlled to ensure that the standard sound is presented first during half of the time and the comparison sound is presented first during the other paired presentations.

Data obtained using this method are reported to be more "regular" than findings of investigators using the Fletcher and Munson approach. Robinson's equal loudness contours exhibited some interesting properties not previously reported. The relations connecting sound pressure level, expressed in decibels, with equivalent loudness, in phons, are accurately expressible by formula quadratic in the sound pressure level. These formulae are expressed by means of parameters which are functions of the frequency, the sensation level of the tone, and the age of the observers. This has enabled compact tables to be prepared for the equivalent loudness of pure tones over the range of measurement.

At frequencies above 1000 Hz, the age of the observers is an important factor, becoming dominant at 15,000 Hz. At the lower frequencies, a lower threshold level has been found (as compared with earlier data), and in the region of 500 Hz, there is a consistent depression in the contours.

This work by Robinson is largely a refinement of the techniques used by Fletcher and Munson as well as by Stevens and therefore is a methodological advance rather than one which is innovative in terms of concept or subject matter.

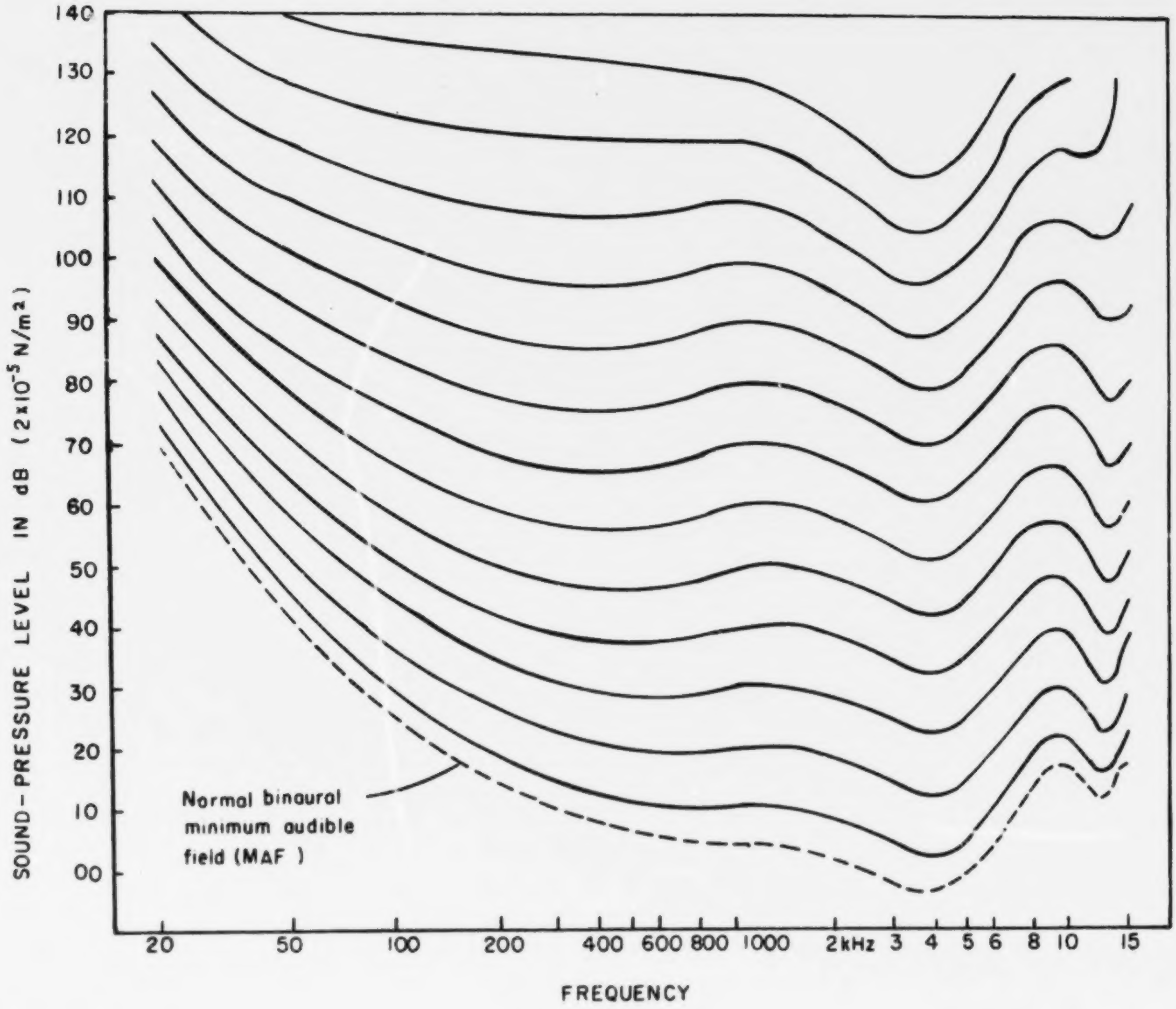

Figure 11. Normal equal-loudness contours for pure tones (binaural free field listening) developed by Robinson and Dadson in Great Britain.

Zwicker's work and interests encompass not only direct loudness measures but the relationship of loudness to masking. Since the loudness contours he developed are designed to explain a series of diverse but related phenomena, they are quite complex and levels are quite difficult to compute. The work of Zwicker and his followers, like that of Stevens, is quite diverse and is generously represented in the open literature. Like Stevens, Zwicker has been very influential in the development of new international standards concerning loudness.

Zwicker's approach is based upon the work of his predecessors (Fletcher and Munson as well as Stevens). His basic assumption is that the loudness unit, the sone, should be based upon a narrow band of noise rather than a pure tone. His rationale is based upon physiological data (known properties of the cochlea) as well as upon behavioral data collected in masking experimentation.

Sones and phons in the Zwicker system carry the subscripts GF (critical bandwidth, free field) or GD (critical bandwidth, diffuse field) depending on whether the test is to be made in the open or in a room. Since the method is primarily graphical, there are several charts required, depending on the particular conditions of the test. These charts differ chiefly in the range of band-levels encompassed by the contours. Loudness levels are computed based upon the total area of the chart "covered" by the noise being evaluated.

In spite of the fact that in noise abatement and control one is usually concerned with complex sounds rather than with pure tones or narrow bands of noise, the equal loudness contours provide the initial empirical data base for estimating the loudness (and, later, noisiness) of complex sounds. The International Organization for Standardization has recommended (ISO R532) Stevens' method for calculating the loudness of steady complex sounds for which octave band analyses are appropriate and has recommended Zwicker's more complicated method for calculating loudness from one-third octave band data. Zwicker's method is better suited than Steven's technique for handling sounds with strong line spectra or irregular spectra. It should be noted that the loudnesses, or loudness levels, obtained by the two methods do not always agree. However, for sounds of similar spectra, the two methods are generally successful in producing consistent results in studies designed to obtain rank orders of the loudness levels (LL) of sounds.

A possible difficulty with all of the above procedures used to date is that they are based on a 1000 Hz tone or band of noise as a reference. It is not axiomatic that two sounds, each of which is judged to be equal in loudness to a 1000 Hz reference sound, would be judged to be equal to each other.

Because of its importance as a noise source, a number of techniques have been developed especially to measure and evaluate aircraft noise. The man usually associated with the refinement of these measurement methods is Karl Kryter who states that "Peoples attributes toward the unwantedness of sounds are in part determined by their masking, loudness, startle, distractive and auditory fatigue effects." Kryter indicates that these effects are perhaps sufficiently similarly determined by the spectral characteristics of sounds to make practical the measurement, in a statistical sense, of an average perceived noisiness aspect of sounds.

A scale was developed to express perceived noisiness (PN) based on occurrences of sound of equal duration. The unit of perceived noisiness is the noy. A sound judged to be subjectively equal in noisiness to an octave band of random noise centered at 1000 Hz and a sound pressure level of 40 dB is given a value of 1 noy; a sound judged as twice as noisy is 2 noy, etc. PN's may be converted to a log scale, judged perceived noise level (PNL) scale. The judged PNL of a given sound is equal numerically to the maximum over-all sound pressure level of a reference sound that is judged by listeners at any given point in time to have the same perceived noisiness as the given sound, the reference sound being random "pink" noise (spectrum level sloping at a rate of -3 dB/octave) precisely one octave in width centered at 1000 Hz and of comparable temporal characteristics as the given sound, i.e., rise and decay times and total duration.

PNL is computed in almost the same way as is the loudness level in Stevens' recent formulation. There are two exceptions: (1) the octave band levels used for evaluating an aircraft flyover are to be the maximum values attained in each band during the event, regardless of when these peaks occur and (2) instead of assigning loudness indices to each measured band level, a corresponding contribution to "perceived noisiness" is assigned for each band in units of "noy."

PNdB was coined as the name of the unit of PNL calculated for a sound. The PNdB unit is the translation of the subjective noy scale to a dB-like scale; an increase of 10 PNdB in a sound is equivalent to a doubling of its noy value.

The PNL procedures are intended to apply to sounds regardless of source or spectral or temporal characteristics. They apply to sounds which either do not convey meaning to the listener or where meaning is kept constant for sounds being compared.

Although PNL was developed because of the inadequacy of loudness based judgments on complex stimuli such as aircraft noise, it was found that the PNL measures were deficient as well, especially for jet aircraft noise. Investigators determined that tonal components within broad band noise and flyover duration both had to be taken into account in any evaluation procedure. As a result of these findings, Effective Perceived Noise Level (EPNL) was introduced. EPNL was defined as PNL + C (tone correction) + D (duration correction) in EPNdB. This measure, derived from instantaneous perceived noise level values, is used by the Federal Aviation Administration in aircraft type certification.

Using PNL as a basic measure, Kryter has suggested several other procedures to be used in special cases, (e.g., impulsive character of sound). The interested reader is referred to his recent book for a full discussion [7].

The previous measures are based chiefly upon laboratory conditions while those which follow are more closely tied to real situations.

"Noise criterion" (NC) curves were designed to embody considerations of both speech interference and loudness and have been used extensively to describe acceptable noise conditions in offices and other rooms. The NC curves originated with Beranek, but there are a number of different versions in use at present. The differences among the several sets of curves chiefly reflect different importance being given to loudness. Beranek, et al. [8] have recently reviewed the history of the criterion curves for acceptable noise levels in rooms and have developed a new approach consisting of "preferred noise criterion (PNC) curves." The original "speech communication (SC) criterion curves", published in 1952, were based on the assumption that noise levels in rooms should be low enough to provide good speech communication. No specific consideration was made of either loudness or annoyance. The now widely used noise criterion (NC) curves were first published, by Beranek, in 1957. These curves were based on data which indicated that the acceptability of ambient noise levels in buildings is a function of both speech interference level and of loudness level. The 1971 PNC curves, given in reference [8] and shown in Figure 12 were proposed because of new data, particularly laboratory and field evidence that the allowable levels at low frequencies and at high frequencies should be lower than the levels stated in the old NC curves. Economic considerations of air-handling systems in buildings limit the amount of noise reduction that is practical in many cases, so the proposed PNC curves define "acceptable" noise spectra rather than "more pleasant" noise spectra.

The same paper by Beranek, et al. [8] suggests a noise criteria range for steady background noise as heard in various indoor functional activity areas.

The PNC (or the NC) curves "have only been validated for continuous noise spectra." In the specification of a PNC curve, it is intended that the sound pressure levels in all of the octave frequency bands not exceed the levels given by the chosen curve. Beranek states that, if the spectra are that of continuous noise, it is common practice to permit the noise level in one octave band (only) to exceed the corresponding value on the specified criterion curve by as much as 2 dB, provided the levels in the two adjacent octave bands (one above and one below) are not more than 1 dB below the criterion curve. If the difference between the level in this one band and that in the two adjacent bands (taking into account the slope of the spectrum) is greater than 3 dB, the noise is likely to contain one or more pure-tone components. Pure tones are known to be more annoying than continuous spectra noise and more stringent criteria, say by 5 to 8 dB, should be applied to them individually than to a band of continuous noise. Beranek states that, in general, the PNC curves should not be used to rate noises whose spectra differ significantly from the contour shape.

SC, NC, and PNC curves are intended for application to noises of a continuous nature. There is a need, in predicting the acceptability of interior noise levels, for a metric that takes appropriate account of the time variation of interior noise level.

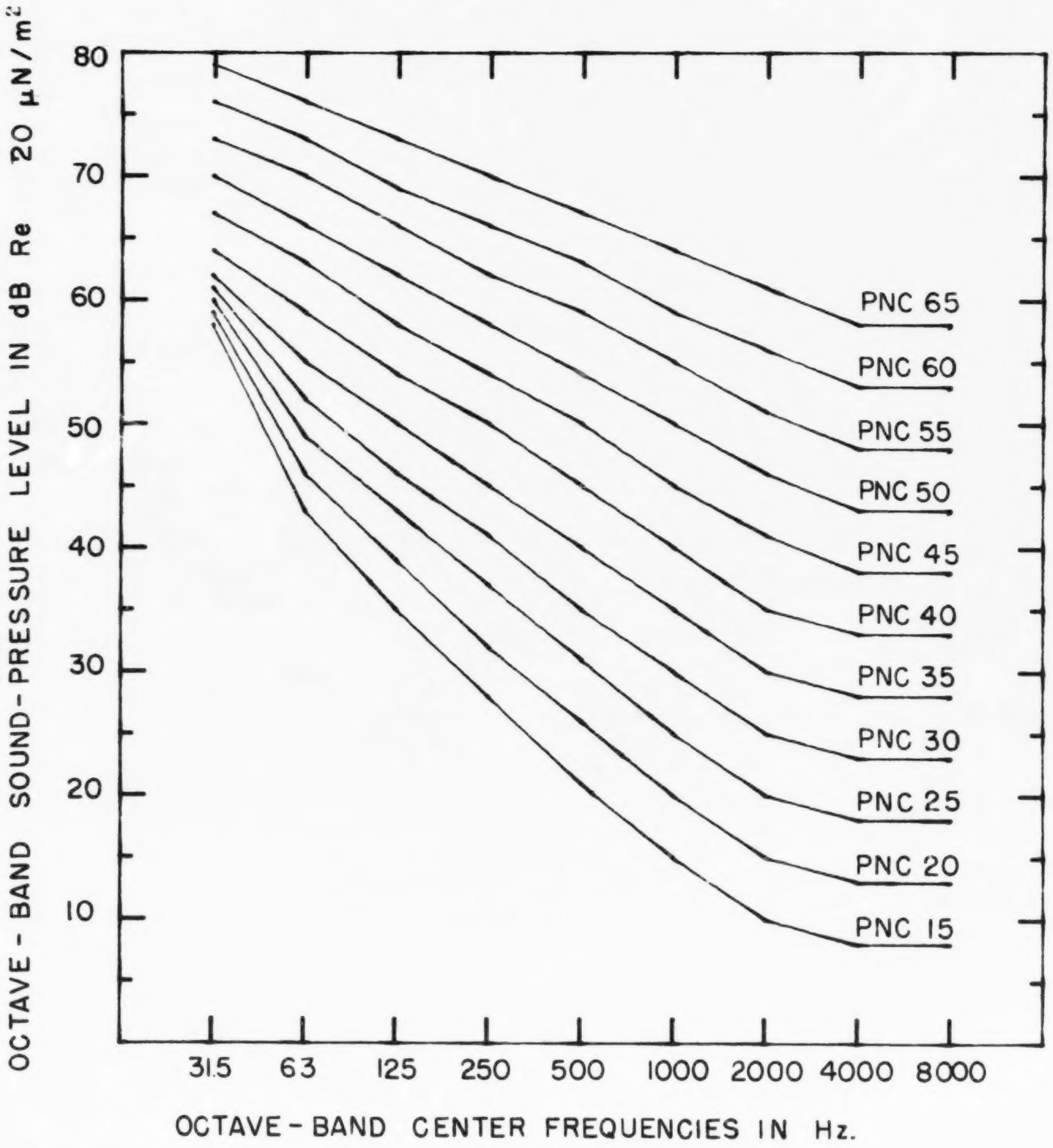

Figure 12. 1971 preferred noise criteria (PNC) curves for rating air handling-system noise in occupied spaces.

Several metrics have been developed which explicitly take into account the time variation of the sound level. The sound level exceeded 10 percent of the time, L_{10}, gives an approximate measure of the higher level, shorter duration sounds, A measure of the median sound level is given by L_{50}, the level exceeded 50 percent of the time. The "residual" sound level can be approximately represented by L_{90}, the sound level exceeded 90 percent of the time. Use has also been made of the "energy mean" noise level, L_{eq}, which is defined as the level of a steady state continuous noise which has the same account of noise energy as the time-average of the actual time varying noise. The quantities L_{90}, L_{50}, L_{10}, and L_{eq}, can be based on several types of measure, such as LL or PNL, but usually are based on the A-weighted sound level.

In order to obtain a more realistic measure of the noise environment created by highways, a series of experiments was conducted by the staff of the Building Research Station at a number of sites in the London area. Dissatisfaction with the noise conditions, obtained by interview questionnaire, was compared to noise level measurements for a 24-hour period taken adjacent to the home of the interviewees. The evaluation of the data led to a new measure, Traffic Noise Index (TNI), defined as

$$\mathrm{TNI} = 4\ (L_{10} - L_{90}) + L_{90} - 30,$$

where L_{10} and L_{90} are the A-weighted sound levels exceeded 10 and 90 percent of the time, respectively, [10, 11].

In an effort to synthesize the results of earlier studies relating community reaction and noise level, the concept of Noise Pollution Level (L_{NP}) was recently introduced. This measure is derived from two terms, one involving the "energy mean" of the noise level and one involving the magnitude of the time variation of the noise level. The first term is usually based on the intensity of higher level intruding noises while the second term is primarily influenced by the background noise. The concept embodies the following simple principles:

(1) other things being equal, the higher the noise levels the more the disturbance caused.

(2) other things being equal, the less steady the level of a noise the greater its distracting and hence annoying quality.

The basic definition of Noise Pollution Level is given by:

$$L_{NP} = L_{eq} + k\sigma$$

where L_{eq} is the "energy mean" of the noise level, L, over a specified period, σ is the standard deviation of the instantaneous level considered as a statistical time series over the same period, and k is a constant provisionally assigned the value 2.56. The noise level L is to be measured on a scale (such as L_A or PNL) which is adequately related to subjective noisiness. The history of the Noise Pollution Level concept and its relation to other measures have been recently described [12]. When the findings obtained using L_{NP} measures were compared with existing survey data, high correlations resulted. If these results are verified in other investigations, the L_{NP} might be an important means of linking the findings obtained in previously unrelated studies. Thus far there has been no attempt to validate the L_{NP} through direct use in a community survey. Such validation is needed to fulfill the promise of the L_{NP} as a common metric for physical characterization of time-varying noise environments.

The majority of the work on developing techniques for estimating community response to noise has been done in the context of aircraft noise, with some additional work on traffic noise. These techniques use as a "basic building block" the noises produced by individual airplanes. These data are then combined to take into account the number and nature of the aircraft operations for the particular airport under consideration. European measures, such as the British Noise and Number Index (NNI), apply a correction based on the total number of aircraft operations, regardless of when they occur. The two U. S. measures, the Composite Noise Rating (CNR) and the more recent Noise Exposure Forecast (NEF), each give a much heavier weighting to operations at night than those during the day--reflecting the higher degree of annoyance caused by night flights. The NEF contour calculation procedure is quite complex. It uses EPNL data for each type of aircraft and includes consideration of the mix of aircraft, number of operations, runway utilization, flight path, operating procedures, and time of day. Probably the most important factor not included is the background noise level--at least in the interpretation for the maximum NEF allowable. Another important factor which is not included is the local weather. Wind and, especially, temperature inversions can drastically change the noise exposure at some locations. A notice of proposed rulemaking was presented on 17 September 1971 that outlined the Federal Aviation Administration proposed amendments to Part 36 of the Federal Aviation Regulations (FAR 36) to require altitude and temperature accountability throughout the noise type-certification tests. The next step needed is the inclusion of such corrections in the computation of the NEF contours for specific airport location.

The NEF contours are not interpreted in terms of individual and group reactions; however, since equivalences are given between CNR and NEF contours some guidance may be obtained from the standard CNR procedure which includes estimated responses of residential communities as a function of CNR. The NEF boundaries are set on the basis of residential land use. A shortcoming in these methods is the lack of adequate social data which can be used to develop better estimators of individual and community reactions to aircraft noise. Conversions also have to be developed to translate NEF contours into terms compatible with other measures of community noise.

Details of computing NEF contours, and a discussion of similar procedures used in other countries, are given in a recent Department of Transportation report [9].

The various estimators of subjective response covered thus far have been based entirely on the physical characterization of the noise event. Such metrics as sound level, loudness level, and perceived noise level are related to the sound pressure level, as a function of frequency, at any given moment in time (rigorously, PNL is sometimes calculated from the highest sound pressure level obtained in each frequency band measured--regardless of the time at which each band level achieved its peak value). The Effective Perceived Noise Level includes consideration of the duration of a single "noise event." Such measures as the Traffic Noise Index and the Noise Pollution Level include specific consideration of the statistical variation, with time, of the total noise exposure resulting from a large number of "noise events." For further discussion of these, and many other, metrics based on the physical characterization of noise, the reader is referred to Kryter's book [7], to the recent Department of Transportation study [13] and to the many references contained in these sources.

In a real, as opposed to a laboratory, setting where individuals and groups are exposed to the noises of everyday living, social factors can have as much, or more, effect on the acceptability of sounds as the physical characteristics of the sound. There is a need for estimators which include the physical characteristics of the sound, the temporal variation of the sound, and means for inclusion of social factors. There has been some work done in this regard (see, e.g., [7, 13]) but considerable further research is needed.

All of the estimators of subjective response discussed thus far have been ratings of the noise itself and its direct effects. In addition, rating schemes are needed and used to estimate satisfaction with the sound isolation provided by, for example, partitions within buildings. The Sound Transmission Class (STC)--a single-figure rating based on the sound transmission losses of the partition in the frequency range 125 to 4000 Hz--is used to describe the airborne sound insulation properties of a partition [14]. The Noise Isolation Class (NIC)--a single figure-rating based on the values of noise reduction in the frequency range 125 to 4000 Hz--is the analagous rating of the sound isolation between two rooms within a building regardless of the path of the sound in getting from one room to the other. STC and NIC are reasonably good predictors of the isolation provided against office noise and the sounds of speech. They are not too suitable for predicting the satisfaction with isolation against low frequency noise and hence should be used with caution in conjunction with rooms adjacent to mechanical equipment rooms or with exterior walls exposed to traffic or aircraft noise.

The Impact Insulation Class (IIC) is a proposed rating scheme which is used to estimate satisfaction with the degree to which a floor/ceiling assembly provides isolation against impact sounds, such as footsteps [15]. This method is not universally accepted, chiefly because of concern about the relevance of the test procedure used, and further development is indicated.

References

[1] Guidelines for noise exposure control, Sound and Vibration 4 (11), 21-24 (November, 1970).

[2] Regulations promulgated under the authority of the Occupational Safety and Health Act of 1970, §1910.95, Occupational noise exposure, Federal Register 36 (105), 10518 (May 29, 1971).

[3] Cohen, A., Anticaglia, J., and Jones, H. H., "Sociocusis" -- hearing loss from non-occupational noise exposure, Sound and Vibration 4 (11), 12-20 (November 1970).

[4] Coles, R. R. A., Garinther, G. R., Hodge, D. C., and Rice, C. G., Hazardous exposure to impulse noise, J. Acoust. Soc. Amer. 43 (2), 336-43 (1968).

[5] Ward, W. D., et al., Proposed damage-risk criterion for impulse noise (gunfire), Report of Working Group 57, NAS-NRC Committee on Hearing, Bioacoustics, and Biomechanics (CHABA), (July 1968).

[6] Coles, R. R. A., and Rice, C. G., Towards a criterion for impulse noise in industry, Ann. Occup. Hyg. 13, 43-50 (1970).

[7] Kryter, K. D., The Effects of Noise on Man (Academic Press, New York and London, 1970).

[8] Beranek, L. L., Blazier, W. E., and Figwer, J. J., Preferred noise criterion (PNC) curves and their application to rooms, J. Acoust. Soc. Amer. 50, 1223-28 (1971).

[9] A Study of the Magnitude of Transportation Noise Generation and Potential Abatement, Volume III, Airport/Aircraft System Noise, Report No. OST-ONA-71-1, Vol. III (November, 1970).

[10] Griffiths, I. D., and Langdon, F. J., Subjective response to road traffic noise, J. Sound Vibration 8, 16 (1968).

[11] Langdon, F. J., and Scholes, W. E., The traffic noise index: a method of controlling noise nuisance, Bldg. Res. Station Current Paper 38168 (1968); Arch. J. 147 (April 1968).

[12] Robinson, D. W., Towards a unified system of noise assessment, J. Sound Vibration 14, 279-98 (1971).

[13] A Study of the Magnitude of Transportation Noise Generation and Potential Abatement, Volume II, Measurement Criterion, Report No. OST-ONA-71-1, Vol. II (November 1970).

[14] ASTM Tentative Classification, E413-70T, for Determination of Sound Transmission Class, 1970 Annual Book of ASTM Standards, Part 14 (Amer. Soc. for Testing and Materials, Philadelphia, 1971).

[15] Proposed Method, RM 14-4, of Laboratory Measurement of Impact Sound Transmission through Floor-Ceiling Assemblies Using the Tapping Machine, Appendix A1, Classification of Floor-Ceiling Assemblies for General Impact Noise Control Purposes (Amer. Soc. for Testing and Materials, Philadelphia, 1971).

5. Example Calculations for Sound Level, Loudness Level, and Perceived Noise Level

The perception of sound by the human ear is a very complicated process. Present state-of-the-art knowledge does not allow for the design of an objective measuring apparatus or computation method which gives results which are absolutely comparable with those given by direct subjective methods for all types of noise. This is the reason for the existence of the numerous rating methods which were discussed in the preceeding section.

To reinforce an understanding of these rating methods and to provide a common base for comparison purposes, the following illustrative examples showing the step by step procedure for computing the overall sound pressure level; A, B, and C-weighted sound level; loudness level by both the Stevens and Zwicker methods; and perceived noise level (including the tone correction) for a given spectrum are developed. The spectrum chosen is that of an executive jet aircraft at 500 feet altitude during an approach operation (figure 13).

5.1. Sound Level

As was discussed previously the decibel is defined as ten times the logarithm to the base ten of the ratio between two like quantities. In acoustics, it is customary for these quantities to have the units of power or to be proportional to power. Since the sound power normally is related to the square of the sound pressure a convenient scale for noise measurements is defined as:

$$\text{Sound Pressure level} = 10 \log_{10}(p^2/p_o^2)$$

where p is the sound pressure being measured
p_o is the reference sound pressure, 20 μN/m^2.

The simplest physical measure of noise is its overall sound pressure level, but such a measure gives little information as to the human perception of the noise. Even though a simple frequency weighting may not be sufficient, it will often give an indication as to the noise perception and presently three standardized weighting curves exist (IEC Recommendation 179 and ANSI S1.4-1971) called A, B and C.

The following pages contain the computation of the A, B and C-weighted sound level for the aircraft noise. Each page contains six columns which are described as follows:

1. Column 1 contains the one-third octave band center frequencies extending from 10 Hz to 20,000 Hz.

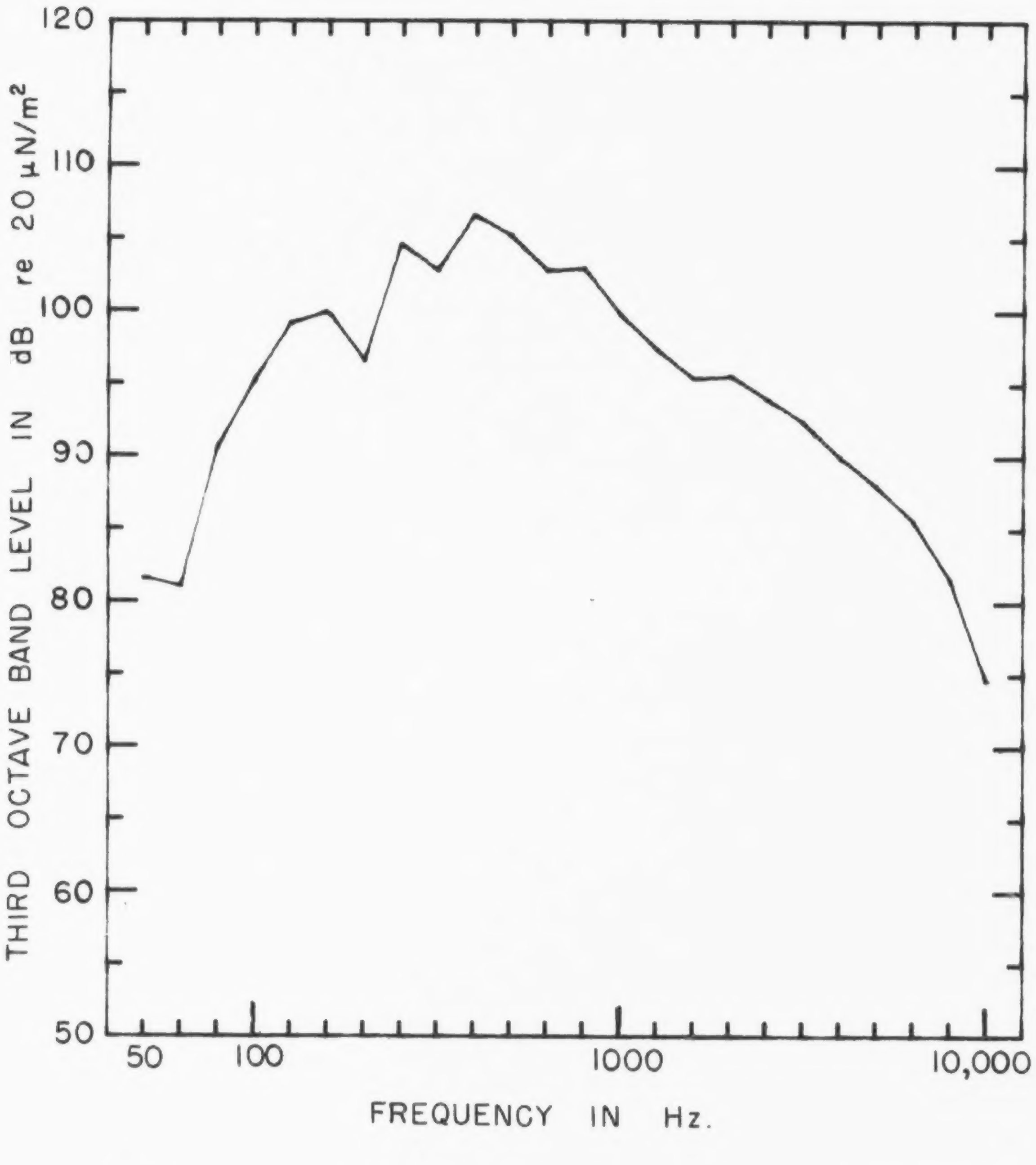

Figure 13. One-third octave band levels for an executive jet aircraft at an altitude of 500 feet during an approach operation.

2. Column 2 contains the sound pressure level in each one-third octave band as measured during the aircraft flyover. This column is labelled L.

3. Column 3 gives the weighting factors, either A, B or C, to be applied in determining the weighted sound level. This column is labelled W.

4. Column 4 gives the weighted level, which is the measured sound pressure level (L) plus the weighting (W), divided by 10. This column is labelled X. Therefore $X = (L+W)/10$.

5. Since the sound pressure level is defined as $10 \log_{10} (p^2/p_o^2)$, the squared pressure ratio (Y) as given in column 5 is equal to 10^x.

6. The total summation of Y is taken and $10 \log_{10} (\Sigma Y)$ is equal to the weighted sound level being calculated.

7. Column 6 gives the relative contribution made by the level in any given frequency band and is simply the value Y divided by the total summation of Y.

In the case of overall sound pressure level calculation the procedure utilized for computing the weighted sound levels is applied except that the weightings are all zero.

5.2. Loudness Level

Two methods (ISO Recommendation 532 Methods A and B) will be illustrated for calculating the loudness or loudness level of a complex sound. These methods differ not only in the method of analysis of the sound, but also in the principles of computation. Method A, or Stevens' method, utilizes physical measurements obtained from spectrum analysis in terms of octave bands and should be used only when the sound spectrum is relatively smooth and the sound contains no pure tones. Also, the method is only applicable to diffuse sound fields. Method B, or Zwicker's method, utilizes spectrum analysis in terms of one-third octave bands and can be used even when the sound spectrum is very irregular and the sound contains pronounced pure tones.

In addition to the different bandwidths involved in the basic physical measurements, the two methods differ in other respects and the results obtained do not always agree. The Zwicker method usually gives slightly higher results than those obtained for the same sounds using the Stevens' method, the difference being possibly as great as 5 phons; but it seems to better account for the variations in sound spectra that occur within narrow ranges of frequency. Example calculations for both methods will be discussed here.

500 FOOT JET APPROACH

FREQUENCY	SIGNAL LEVEL, L	DB(A) WEIGHT, W	WEIGHTED LEVEL, X	SQUARED PRESSURE RATIO, Y	RELATIVE CONTRIBUTION OF Y
HZ	DB	DB	BEL	--	--
10.0	--	-70.4	--	--	--
12.5	--	-63.4	--	--	--
16.0	--	-56.7	--	--	--
20.0	--	-50.5	--	--	--
25.0	--	-44.7	--	--	--
31.5	--	-39.4	--	--	--
40.0	--	-34.6	--	--	--
50.0	81.6	-30.2	5.14	.138+06*	.000
63.0	81.0	-26.2	5.48	.302+06	.000
80.0	90.6	-22.5	6.81	.646+07	.000
100.0	95.2	-19.1	7.61	.407+08	.000
125.0	99.2	-16.1	8.31	.204+09	.002
160.0	100.0	-13.4	8.66	.457+09	.004
200.0	96.6	-10.9	8.57	.372+09	.004
250.0	104.6	-8.6	9.60	.398+10	.039
315.0	102.8	-6.6	9.62	.417+10	.041
400.0	106.6	-4.8	10.18	.151+11	.148
500.0	105.2	-3.2	10.20	.158+11	.155
630.0	102.8	-1.9	10.09	.123+11	.120
800.0	103.0	-.8	10.22	.166+11	.162
1000.0	99.8	.0	9.98	.955+10	.093
1250.0	97.4	.6	9.80	.631+10	.062
1600.0	95.4	1.0	9.64	.437+10	.043
2000.0	95.6	1.2	9.68	.479+10	.047
2500.0	94.0	1.3	9.53	.339+10	.033
3150.0	92.4	1.2	9.36	.229+10	.022
4000.0	90.0	1.0	9.10	.126+10	.012
5000.0	88.0	.5	8.85	.708+09	.007
6300.0	85.6	-.1	8.55	.355+09	.003
8000.0	81.6	-1.1	8.05	.112+09	.001
10000.0	74.6	-2.5	7.21	.162+08	.000
12500.0	--	-4.3	--	--	--
16000.0	--	-6.6	--	--	--
20000.0	--	-9.3	--	--	--
SUM Y				.102+12	
DB(A) = 10 LOG(SUM Y)				110.1	

---

*The notation .138 + 06 means .138 x 10^6 = 138,000.

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500 FOOT JET APPROACH



                                                       SQUARED       RELATIVE
FREQUENCY    SIGNAL        DB(B)       WEIGHTED       PRESSURE     CONTRIBUTION
             LEVEL, L    WEIGHT, W     LEVEL, X       RATIO, Y         OF Y

   HZ           DB           DB           BEL            --             --


   10.0         --         -38.2          --             --             --
   12.5         --         -33.2          --             --             --
   16.0         --         -28.5          --             --             --
   20.0         --         -24.2          --             --             --
   25.0         --         -20.4          --             --             --
   31.5         --         -17.1          --             --             --
   40.0         --         -14.2          --             --             --
   50.0        81.6        -11.6         7.00         .100+08          .000
   63.0        81.0         -9.3         7.17         .148+08          .000
   80.0        90.6         -7.4         8.32         .209+09          .001
  100.0        95.2         -5.6         8.96         .912+09          .005
  125.0        99.2         -4.2         9.50         .316+10          .017
  160.0       100.0         -3.0         9.70         .501+10          .027
  200.0        96.6         -2.0         9.46         .288+10          .015
  250.0       104.6         -1.3        10.33         .214+11          .114
  315.0       102.8          -.8        10.20         .158+11          .085
  400.0       106.6          -.5        10.61         .407+11          .217
  500.0       105.2          -.3        10.49         .309+11          .165
  630.0       102.8          -.1        10.27         .186+11          .099
  800.0       103.0           .0        10.30         .200+11          .107
 1000.0        99.8           .0         9.98         .955+10          .051
 1250.0        97.4           .0         9.74         .550+10          .029
 1600.0        95.4           .0         9.54         .347+10          .019
 2000.0        95.6          -.1         9.55         .355+10          .019
 2500.0        94.0          -.2         9.38         .240+10          .013
 3150.0        92.4          -.4         9.20         .158+10          .008
 4000.0        90.0          -.7         8.93         .851+09          .005
 5000.0        88.0         -1.2         8.68         .479+09          .003
 6300.0        85.6         -1.9         8.37         .234+09          .001
 8000.0        81.6         -2.9         7.87         .741+08          .000
10000.0        74.6         -4.3         7.03         .107+08          .000
12500.0         --          -6.1          --             --             --
16000.0         --          -8.4          --             --             --
20000.0         --         -11.1          --             --             --

SUM Y                                                 .187+12

DB(B) = 10 LOG(SUM Y)                                 112.7
```

NOT REPRODUCIBLE

500 FOOT JET APPROACH

FREQUENCY	SIGNAL LEVEL, L	DB(C) WEIGHT, W	WEIGHTED LEVEL, X	SQUARED PRESSURE RATIO, Y	RELATIVE CONTRIBUTION OF Y
HZ	DB	DB	BEL	--	--
10.0	--	-14.3	--	--	--
12.5	--	-11.2	--	--	--
16.0	--	-8.5	--	--	--
20.0	--	-6.2	--	--	--
25.0	--	-4.4	--	--	--
31.5	--	-3.0	--	--	--
40.0	--	-2.0	--	--	--
50.0	81.6	-1.3	8.03	.107+09	.000
63.0	81.0	-.8	8.02	.105+09	.000
80.0	90.6	-.5	9.01	.102+10	.005
100.0	95.2	-.3	9.49	.309+10	.014
125.0	99.2	-.2	9.90	.794+10	.036
160.0	100.0	-.1	9.99	.977+10	.044
200.0	96.6	.0	9.66	.457+10	.021
250.0	104.6	.0	10.46	.288+11	.131
315.0	102.8	.0	10.28	.191+11	.087
400.0	106.6	.0	10.66	.457+11	.208
500.0	105.2	.0	10.52	.331+11	.151
630.0	102.8	.0	10.28	.191+11	.087
800.0	103.0	.0	10.30	.200+11	.091
1000.0	99.8	.0	9.98	.955+10	.043
1250.0	97.4	.0	9.74	.550+10	.025
1600.0	95.4	-.1	9.53	.339+10	.015
2000.0	95.6	-.2	9.54	.347+10	.016
2500.0	94.0	-.3	9.37	.234+10	.011
3150.0	92.4	-.5	9.19	.155+10	.007
4000.0	90.0	-.8	8.92	.832+09	.004
5000.0	88.0	-1.3	8.67	.468+09	.002
6300.0	85.6	-2.0	8.36	.229+09	.001
8000.0	81.6	-3.0	7.86	.724+08	.000
10000.0	74.6	-4.4	7.02	.105+08	.000
12500.0	--	-6.2	--	--	--
16000.0	--	-8.5	--	--	--
20000.0	--	-11.2	--	--	--
SUM Y				.220+12	
DB(C) = 10 LOG(SUM Y)				113.4	

```
500 FOOT JET APPROACH



                                                          SQUARED     RELATIVE
FREQUENCY     SIGNAL          DB(L)       WEIGHTED      PRESSURE    CONTRIBUTION
              LEVEL, L    WEIGHT, A      LEVEL, X      RATIO, Y       OF Y

   HZ            DB           DB            REL            --           --


   10.0          --           --            --             --           --
   12.5          --           --            --             --           --
   16.0          --           --            --             --           --
   20.0          --           --            --             --           --
   25.0          --           --            --             --           --
   31.5          --           --            --             --           --
   40.0          --           --            --             --           --
   50.0         81.6          --           8.16         .145+09        .001
   63.0         81.0          --           8.10         .126+09        .001
   80.0         90.6          --           9.06         .115+10        .005
  100.0         95.2          --           9.52         .331+10        .015
  125.0         99.2          --           9.92         .832+10        .037
  160.0        100.0          --          10.00         .100+11        .045
  200.0         96.6          --           9.66         .457+10        .021
  250.0        104.6          --          10.46         .288+11        .130
  315.0        102.8          --          10.28         .191+11        .086
  400.0        106.6          --          10.66         .457+11        .206
  500.0        105.2          --          10.52         .331+11        .149
  630.0        102.8          --          10.28         .191+11        .086
  800.0        103.0          --          10.30         .200+11        .090
 1000.0         99.8          --           9.98         .955+10        .043
 1250.0         97.4          --           9.74         .550+10        .025
 1600.0         95.4          --           9.54         .347+10        .016
 2000.0         95.6          --           9.56         .363+10        .016
 2500.0         94.0          --           9.40         .251+10        .011
 3150.0         92.4          --           9.24         .174+10        .008
 4000.0         90.0          --           9.00         .100+10        .005
 5000.0         88.0          --           8.80         .631+09        .003
 6300.0         85.6          --           8.56         .363+09        .002
 8000.0         81.6          --           8.16         .145+09        .001
10000.0         74.6          --           7.46         .288+08        .000
12500.0          --           --            --             --           --
16000.0          --           --            --             --           --
20000.0          --           --            --             --           --

SUM Y                                                   .222+12

DB(L) = 10 LOG(SUM Y)                                   113.5
```

NOT REPRODUCIBLE

a. Stevens' Method

Addition of partial loudnesses is the fundamental notion in all of the procedures for calculating loudness. In Stevens' method, partial loudnesses are determined by means of a family of curves (figure 14) from sound levels which are measured in octave frequency bands. These partial loudnesses are called indices. The procedure is as follows:

Step 1. Convert each octave band sound pressure level into a loudness index by means of the curves shown in Figure 14 .

Step 2. Compute the total loudness in sones S_t by means of the formula

$$S_t = S_m + F\ (\Sigma S - S_m)$$

where a) S_m is the greatest of the loudness indices
b) ΣS is the sum of the loudness indices for all the bands.
c) F is a constant equal to 0.3 for octave bands.

Partial masking is taken into account very generally by multiplying all the loudness indices, except the one with the largest number, by a factor smaller than 1.

Step 3. The total loudness is them converted into calculated loudness level in phons by means of the formula

$$P = 40 + 10\ \log_2 S_t$$

Included in figure 14 is a nomograph of this relation.

Normally, the calculated loudness is labeled sones (OD) and the loudness level is labeled phons (OD) to designate that they have been calculated from octave-band levels (O) and for a diffuse field (D). The spectrum utilized for the example calculation shown on the following pages is based on the outdoor measurement of aircraft flyover noise and therefore the sound field is not diffuse. Rather than choose a specialized spectrum to illustrate the computation procedure for the Stevens method, the aircraft spectrum was utilized. The procedure for computing octave band levels from 1/3-octave levels -- a procedure that normally would only be utilized to compare two sets of data obtained using different bandwidth analyzers -- is shown in Appendix C.

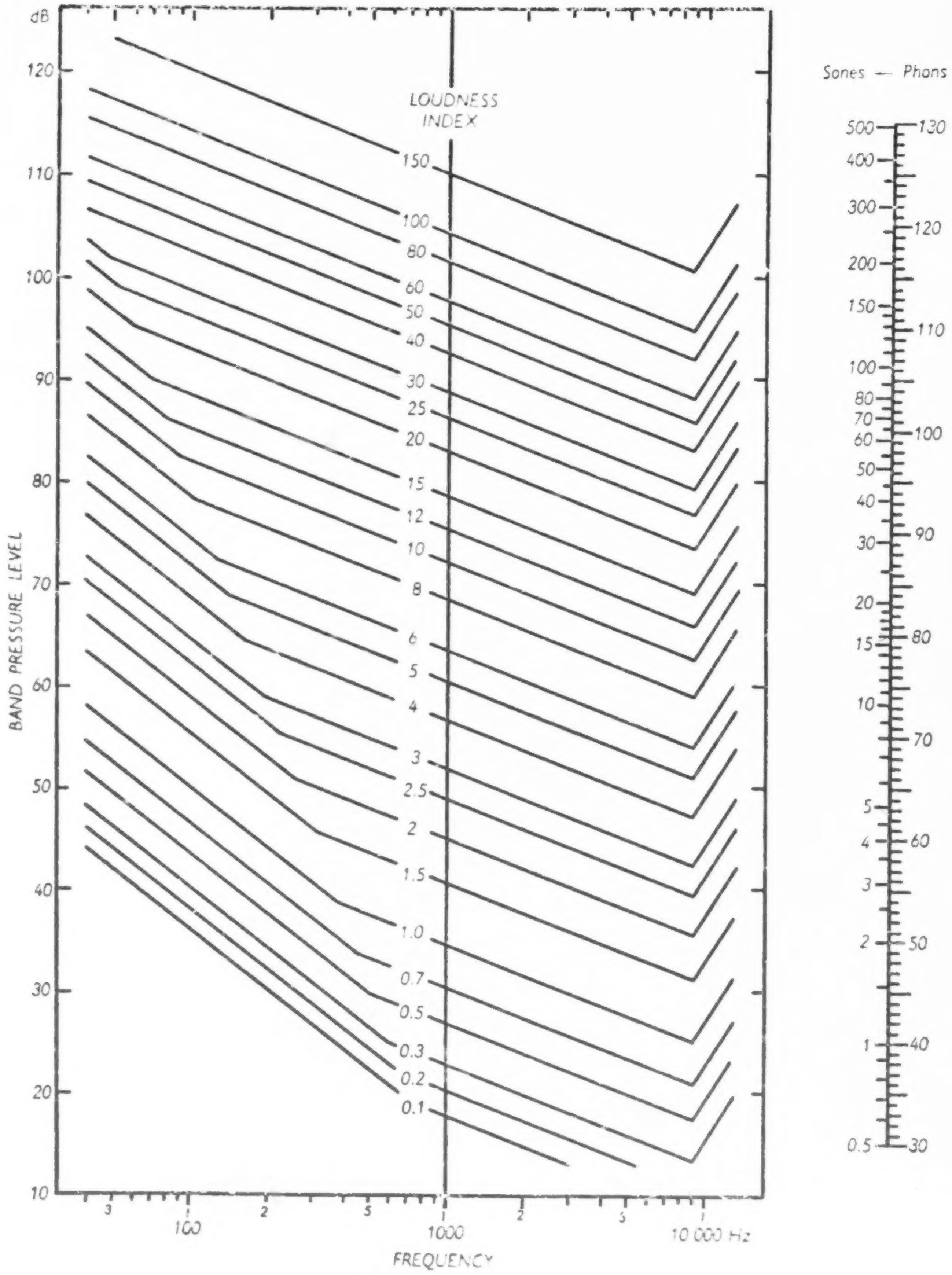

Figure 14. Curves for determining loudness indices used in Stevens' method of calculating loudness.

```
STEVENS SONES, PHONS, FROM OCTAVE BAND LEVELS

 500 FOOT JET APPROACH

                        FREQUENCY  SIGNAL  LOUDNESS
                                   LEVEL   INDEX

                           HZ        DB      --

                          63.0      91.5     15.3
                         125.0     103.4     44.0
                         250.0     107.2     77.0
                         500.0     109.9    121.0
                        1000.0     105.4    105.0
                        2000.0      99.8     90.0
                        4000.0      95.3     77.0
                        8000.0      87.3     52.0

SUM OF LOUDNESS INDICES                     581.3
SUBTRACT MAXIMUM LOUDNESS INDEX            -121.0

                                            460.3
MULTIPLY BY .3                             X   .3

                                            138.1
ADD MAXIMUM LOUDNESS INDEX                 +121.0

SONES                                       259.1

LOG2 SONES = (LOG10 SONES)/.301               8.02
                                           X 10.
MULTIPLY BY 10.
                                             80.2
ADD 40.                                    + 40.

PHONS                                       120.2
```

NOT REPRODUCIBLE

b. Zwicker's Method

The Zwicker Method (Method B of ISO Recommendation 532) specifies a procedure for calculating the loudness of steady complex sounds for which one-third octave band analyses have been obtained. The loudness level in phons is calculated by means of a formula (discussed below) or from the nomograph of the formula shown on Figure 15.

The procedure for the calculation of loudness level consists of three steps.

Step 1. Select a graph (there are 8 different Zwicker diagrams) which corresponds to the appropriate type of sound field and which includes the highest one-third octave band level measured. Draw the measured levels in the bands above 280 Hz as horizontal lines so that the cut-off frequencies of the one-third octave bands correspond to the abscissa of the graph and the measured levels correspond to the numbering of the stepped curves. At lower frequencies the one-third octave band data are grouped as follows to obtain corresponding band levels L_1, L_2 and L_3 before entering them on the diagram.

(1) Combine all bands with center frequencies up to 80 Hz (L_1)

(2) Combine the bands with center frequencies of 100, 125 and 160 Hz (L_2)

(3) Combine the bands with center frequencies of 200 and 250 Hz (L_3)

The rule of combination may be understood from the example:

$$L_2 = 10 \log_{10} (\text{antilog } L_{100}/10 + \text{antilog } L_{125}/10 + \text{antilog } L_{160}/10)$$

where L_{100}, etc. is the measured one-third octave band pressure level for the band with a center frequency of 100 H_z. Draw each of these combined levels as a horizontal line of the width of the combined band, so that the levels correspond to the numbering of the stepped curves.

Step 2. Where the steps formed by these horizontal lines are rising with frequency, the adjacent horizontal levels are connected by vertical lines at the frequency separating the two bands. When the level in the next highest frequency band is lower, the fall is drawn as a downward sloping curve interpolated between the dashed curves on the graph, starting from the right-hand end of the horizontal line. The area enclosed by the whole stepped figure so obtained corresponds to the total loudness.

Step 3. Transform the enclosed area into a rectangle of the same area and having a base equal to the width of the graph by means of a planimeter. The height of the rectangle gives directly the loudness level in phons (GF*) or (GD) from the scales on either side of the graph. The corresponding loudness in sones (GF) or (GD) may be read from the second scale or computed from the relation:

$$P = 40 + 10 \log_2 S_t$$

where S_t is the total loudness in sones.

Figure 15 shows the application of the Zwicker method to the aircraft spectrum shown in Figure 13. The value obtained is 121 phones (GF).

5.3. Perceived Noise Level

A procedure which approximates the subjectively perceived noisiness rather than loudness was developed by K. D. Kryter and is now widely used for aircraft noise measurements, particularly aircraft flyovers. In this procedure, the perceived noise level of a given sound is numerically equal to the sound pressure level of a reference sound (the reference sound is a band of random noise, one octave wide, centered at 1000 Hz) that is judged by listeners to be as "noisy" as the given sound. This method recognizes the increased contributions of the higher frequencies to the annoyance of a sound and weights higher frequencies more heavily. Masking is accounted for in the same manner as in the Stevens' method for calculating loudness level.

Instantaneous perceived noise levels (L_{PN}) are calculated from instantaneous one-third octave band sound pressure levels according to the following procedure:

Step 1. The sound pressure level in each one-third octave band from 50 to 10,000 Hz (24 one-third octave bands) is converted to perceived noisiness by finding the proper NOYS value for each band level by means of a special table or by means of the curves shown in figure 16.

---

*For this example it would be GF indicating a critical-band analysis and a free field.

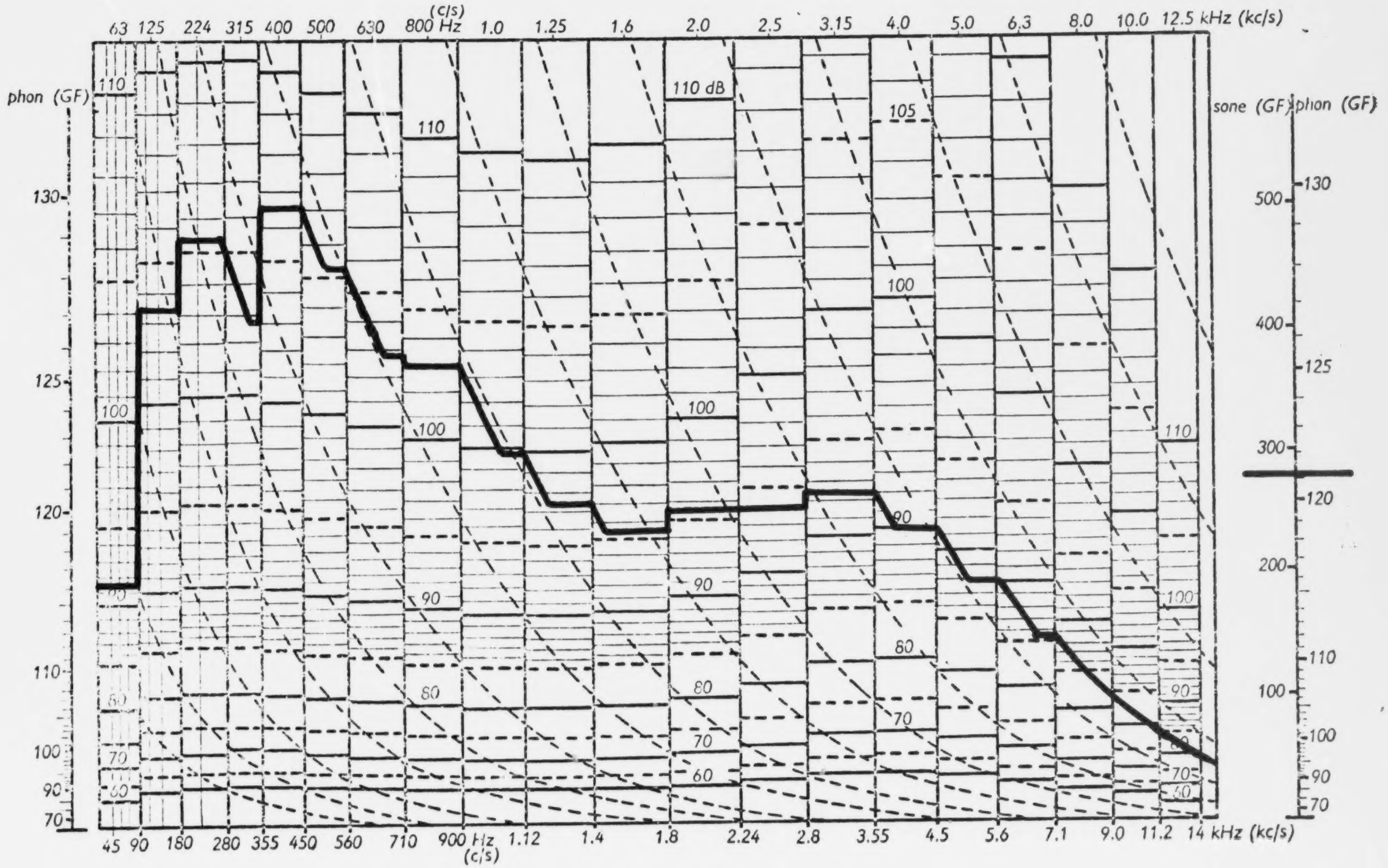

Figure 15. Zwicker diagram with curve representing the analysis of the aircraft sound spectrum shown in Figure 13.

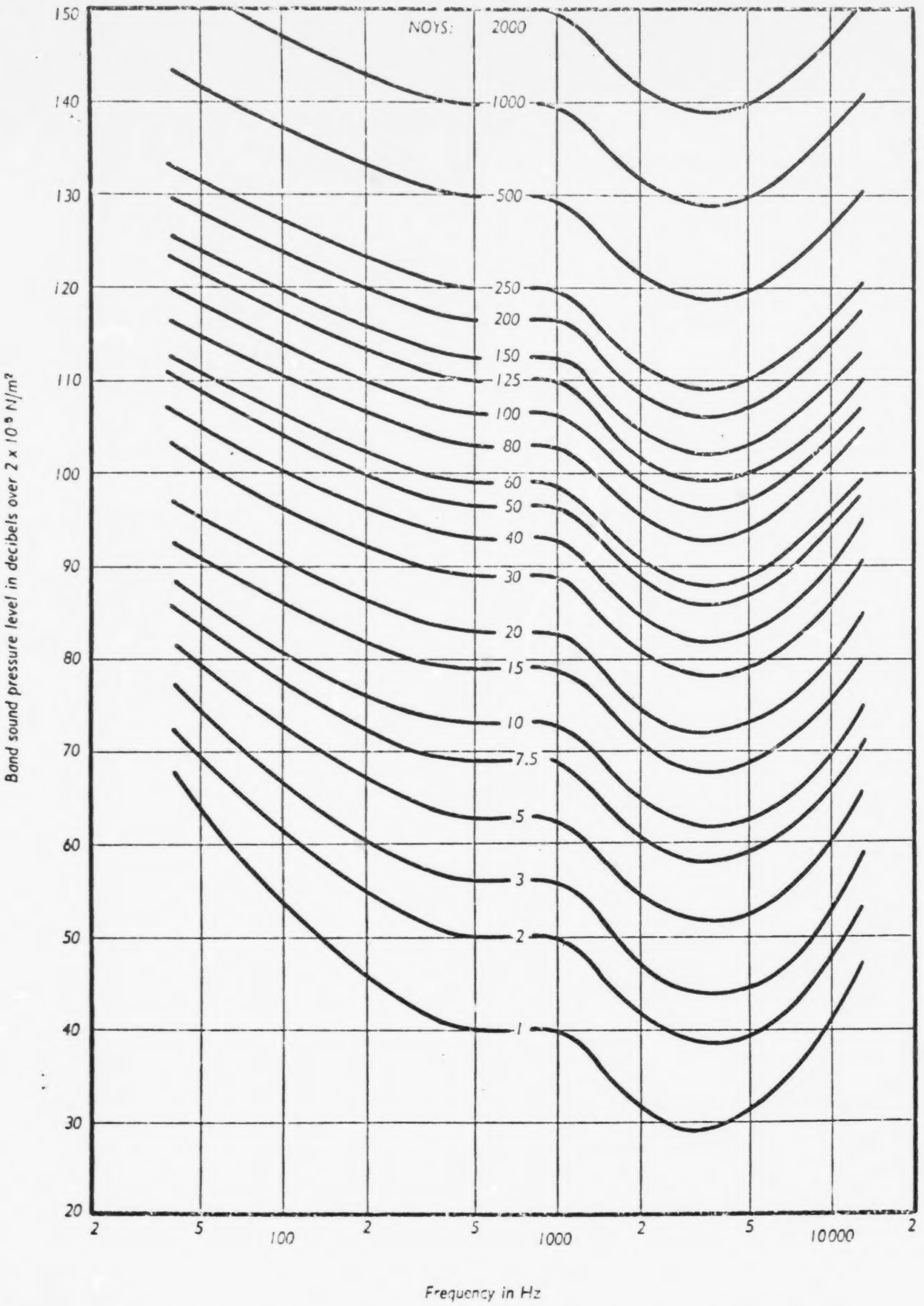

Figure 16. Curves for determining noisiness of bands of sound used in Kryter's method of calculating perceived noisiness.

Step 2. The sum of the values of perceived noisiness in all the one-third octave bands of the spectrum is taken (Σn).

Step 3. The total perceived noisiness (PN) is then calculated as follows:

$$PN = n_m + 0.15 (\Sigma n - n_m)$$

where n_m is the maximum value of perceived noisiness in all bands.

Step 4. The perceived noise level (L_{PN}) in dB (also called PNdB) is calculated from the formula,

$$PNL = 40.0 + 33.3 \log_{10} (PN)$$

or by entering the NOYS curves and picking off the sound pressure level corresponding to the value of total perceived noisiness (PN) at 1000 Hz.

If pure tones, or pronounced irregularities are present in the spectrum, the preceeding calculation should be corrected in the following manner:

Step 1. Starting with the corrected sound pressure level in the 80 Hz one-third octave band (band number 19 according to USAS S1.6-1967, Preferred Frequency Bands), calculate the changes in sound pressure level (slopes) of the one-third octave band as follows:

$$S \text{ (band 3)} = \text{no value}$$

$$\begin{array}{lll} S \text{ (band 4)} = & SPL \text{ (band 4)} - & SPL \text{ (band 3)} \\ \vdots & \vdots & \vdots \\ S \text{ (band 40)} = & SPL \text{ (band 40)} - & SPL \text{ (band 39)} \end{array}$$

Step 2. Calculate the changes in slope ΔS (band S) = S (band 5) - S (band 4) etc. and encircle the value of the slope(s) where the absolute value of ΔS is greater than 5.

Step 3. (a) If the encircled value of the slope (5) is positive and algebraically greater than the slope in the preceeding band encircle the SPL of that band.

(b) If the encircled value of the slope (S) is zero or negative and the slope of the preceeding band is positive, encircle the SPL of the preceeding band.

Step 4. Omit all SPL encircled in Step 3 and compute new sound pressure levels SPL' as follows:

(a) For noncircled sound pressure levels, let the new sound pressure levels equal the original sound pressure levels,

$$\text{SPL}' = \text{SPL}$$

(b) For encircled sound pressure levels in bands 17-39, let the new sound pressure level equal the arithmetic average of the preceeding and following sound pressure levels.

e.g. $$\text{SPL}'(\text{band } 19) = 1/2\ [\text{SPL } (\text{band } 18) + \text{SPL } (\text{band } 20)]$$

(c) If the sound pressure level in the highest frequency band (24) is encircled, let the new sound pressure level in that band equal

$$\text{SPL}'\ (\text{band } 24) = 2\ (\text{SPL } [\text{band } 23])$$

Step 5. Recompute new slopes (S') as follows

$$S'\ (\text{band } 19) = S\ (\text{band } 20)$$

$$S'\ (\text{band } 20) = \text{SPL}'\ (\text{band } 20) - \text{SPL}'\ (\text{band } 19)$$

$$\vdots \qquad \vdots \qquad \vdots$$

Step 6. For bands 19-39 compute the arithmetic as follows

$$\bar{S}\ (\text{band } 19) = 1/3\ [S'\ (\text{band } 19) + S'\ (\text{band } 20) + S'\ (\text{band } 21)] \text{ etc.}$$

Step 7. Compute final adjusted one-third octave band sound pressure levels (SPL") by beginning with band number 19 and proceeding to band number 40 as follows:

$$\text{SPL}''\ (\text{band } 19) = \text{SPL } (\text{band } 19)$$

$$\text{SPL}''\ (\text{band } 20) = \text{SPL}''\ (\text{band } 19) + \bar{S}\ (\text{band } 19) \text{ etc.}$$

Step 8. Calculate the differences (F) between the original and the adjusted sound pressure levels as follows:

$$F\ (\text{band } 19) = \text{SPL } (\text{band } 19) - \text{SPL}''\ (\text{band } 19)$$

and note only values greater than zero.

Step 9. For each of the 24 one-third octave bands, determine tone correction factors from the sound pressure level differences F and the following table

Frequency	Level Difference F, dB	Tone Correction C, dB
$50 \leq f < 500$	$F < 3$ $3 \leq F < 20$ $20 \leq F$	0 F/6 3-1/3
$500 \leq f \leq 5000$	$F < 3$ $3 \leq F < 20$ $20 \leq F$	0 F/3 6-2/3
$5000 < f \leq 10000$	$F < 3$ $3 \leq F < 20$ $20 \leq F$	0 F/6 3-1/3

Table 5-1. Tone Correction Factors

Step 10. Tone Corrected Perceived noise levels are determined by adding the largest of the tone correction factors to the corresponding PNL values, that is,

$$\mathrm{PNLT} = \mathrm{PNL} + C_{max}$$

The perceived noise level and the tone corrected perceived noise level were calculated for the aircraft spectrum shown in Figure 13, The details of the step-by-step computations are shown on the following pages.

5.4 Straight Line Spectra

The above discussion concentrates on only a few of the numerous rating schemes discussed in Section 4. These are all instantaneous single number ratings with no time duration, sociological, or other considerations. It would be extremely convenient if a table of conversion factors could be developed relating a value on any given rating scheme to values obtained using any other method. Of course, this is not possible because the rating schemes are heavily dependent on the shape of the given spectrum. In some cases, however, where the spectrum shape is approximately the same, e.g., aircraft flyovers, a reasonably reliable conversion factor can exist -- $L_A \approx \mathrm{PNL} - 13$.

```
KRYTER PERCEIVED NOISE LEVEL FROM 1/3 OCTAVE BANDS

500 FOOT JET APPROACH

                FREQUENCY   SIGNAL   PERCEIVED
                            LEVEL    NOISINESS

                   HZ         DB        NOYS

                  50.0       81.6       5.8
                  63.0       81.0       7.1
                  80.0       90.6      17.9
                 100.0       95.2      28.2
                 125.0       99.2      39.9
                 160.0      100.0      45.3
                 200.0       96.6      41.1
                 250.0      104.6      76.6
                 315.0      102.8      72.5
                 400.0      106.6     101.1
                 500.0      105.2      91.8
                 630.0      102.8      77.7
                 800.0      103.0      78.8
                1000.0       99.8      63.1
                1250.0       97.4      61.4
                1600.0       95.4      69.1
                2000.0       95.6      80.4
                2500.0       94.0      82.7
                3150.0       92.4      79.3
                4000.0       90.0      67.2
                5000.0       88.0      54.7
                6300.0       85.6      43.2
                8000.0       81.6      26.7
               10000.0       74.6      13.4

SUM OF NOY VALUES                     1325.1
SUBTRACT MAXIMUM NOY VALUE            -101.1

                                      1224.0
MULTIPLY BY .15                       X   .15

                                       183.6
ADD MAXIMUM NOY VALUE                 +101.1

N                                      284.7

LOG N                                    2.45
MULTIPLY BY 33.3                      X33.3

                                        81.7
ADD 40.                               + 40.

PERCEIVED NOISE LEVEL, PNL             121.7

ADD TONE CORRECTION                   +   .8
TONE CORRECTED PERCEIVED
NOISE LEVEL,PNLT                       122.5
```

```
PURE TONE CORRECTION TABLE

BAND     SPL       S      [ASI    SPL*      S*    SBAR    SPL**      F       C
 17    81.60F     .00     .00    81.60     .00     .00     .00     .00     .00
 18    81.00F     .00     .00    81.00     .00     .00     .00     .00     .00
 19    90.60F     .00     .00    90.60    4.60    4.40   90.60     .00     .00
 20    95.20F    4.60     .00    95.20    4.60    3.13   95.00     .20     .00
 21    99.20F    4.00     .60    99.20    4.00     .47   98.13    1.07     .00
 22   100.00F     .80    3.20   100.00     .80     .17   98.60    1.40     .00
 23    96.60F   -3.40    4.20    96.60   -3.40     .93   98.77     .00     .00
 24   104.60T    8.00   11.40    99.70    3.10    2.47   99.70    4.90     .82
 25   102.80F   -1.80    9.80   102.80    3.10    1.83  102.17     .63     .00
 26   106.60T    3.80    5.60   104.00    1.20     .00  104.00    2.60     .00
 27   105.20F   -1.40    5.20   105.20    1.20    -.33  104.00    1.20     .00
 28   102.80F   -2.40    1.00   102.80   -2.40   -1.80  103.67     .00     .00
 29   103.00F     .20    2.60   103.00     .20   -1.80  101.87    1.13     .00
 30    99.80F   -3.20    3.40    99.80   -3.20   -2.53  100.67     .00     .00
 31    97.40F   -2.40     .80    97.40   -2.40   -1.40   97.53     .00     .00
 32    95.40F   -2.00     .40    95.40   -2.00   -1.13   96.13     .00     .00
 33    95.60F     .20    2.20    95.60     .20   -1.00   95.00     .60     .00
 34    94.00F   -1.60    1.80    94.00   -1.60   -1.87   94.00     .00     .00
 35    92.40F   -1.60     .00    92.40   -1.60   -2.00   92.13     .27     .00
 36    90.00F   -2.40     .80    90.00   -2.40   -2.27   90.13     .00     .00
 37    88.00F   -2.00     .40    88.00   -2.00   -2.80   87.87     .13     .00
 38    85.60F   -2.40     .40    85.60   -2.40   -4.47   85.07     .53     .00
 39    81.60F   -4.00    1.60    81.60   -4.00   -6.00   80.60    1.00     .00
 40    74.60F   -7.00    3.00    74.60   -7.00     .00   74.60     .00     .00
TONE CORRECTION=     .82
```

NOT REPRODUCIBLE

In order to illustrate the effect the spectrum shape has on the single number rating schemes, four straight line spectra were chosen to be analyzed. Each of the spectrum chosen covered a frequency range from 10 to 20,000 Hz and was adjusted such that the overall sound pressure level was equal for all of the spectra. Spectra were chosen wherein the 1/3-octave band sound pressure levels change with frequency by the following amounts: (a) -6 dB/octave, (b) 0 dB/octave, (c) +3 dB/octave, and (d) +6 dB/octave.

The overall sound pressure level; A, B and C-weighted sound level; Stevens and Zwicker loudness levels; and Perceived Noise Level were calculated and the results are plotted in figure 17. The detailed step-by-step calculations are given in Appendix D.

A comparison among the single number ratings proves that there exists no table of simple additive constants which would relate all of the rating schemes to one another. For instance the difference between the A-weighted sound level and the perceived noise level ranged from 9.3 - 15.6 dB. Also if it were possible to easily convert from one rating scheme to another then there would be no need for the large number of rating methods available and in use at the present time.

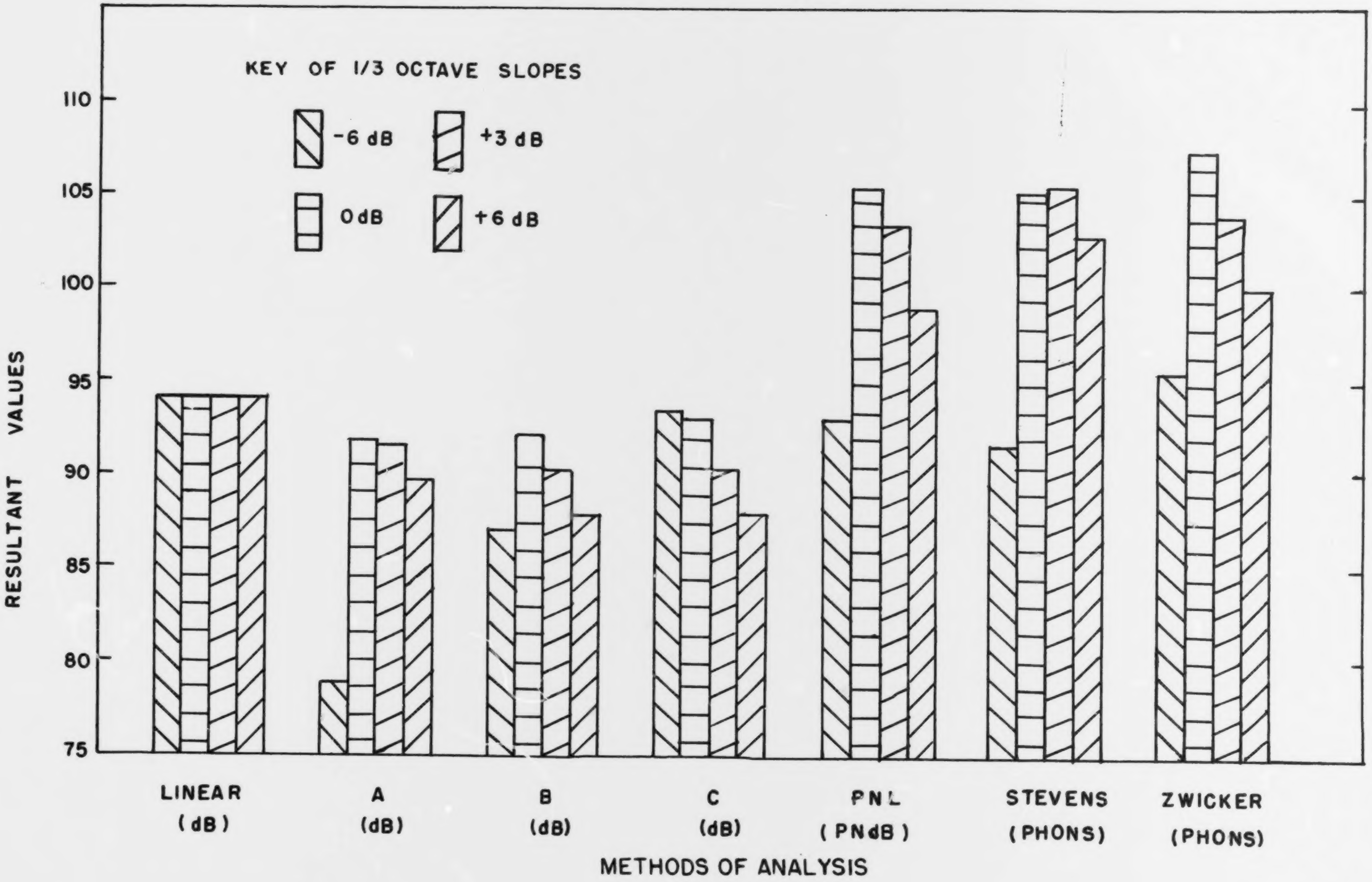

Figure 17. Comparison of the values of overall sound pressure level, sound level, loudness level, and perceived noise level computed for four straight line spectra to illustrate the effect that spectrum shape has on the single number rating schemes.

6. Measurement Systems for Sources in Real World Situations

One would like to make a measurement, or set of measurements, in a well defined acoustic environment that would enable reliable prediction of the noise produced by the source regardless of the environment in which it might be placed. This is a reasonable approach for household devices such as blenders and vacuum cleaners where, for the most part, the noise level produced by the device is dependent on the sound-radiating characteristics of the device itself and on the sound absorbing and reflecting qualities of the space in which the device is used but depends little upon the way the device is installed. Such devices would be characterized by measuring the sound power level according to standard procedures in either a free-field or diffuse-field acoustic environment.

Usually, however, the noise level produced by a specific machine, e.g., a truck or a pavement breaker, is not only dependent upon the sound radiating characteristics of the machine itself but also on the way the machine is operated and the specific environment in which it is used. In setting noise limits for such devices through regulations and labeling standards, test procedures and measurement methodology should include such items as loading, operating speeds, and the environment. Two typical examples will be discussed to show the factors that must be specified in the measurement system to accurately characterize real sources.

The Society of Automotive Engineers has recommended a measurement system (S.A.E.-J-366, Exterior Sound Level for Heavy Trucks and Buses, 1969) for establishing the maximum exterior sound level output of motor trucks, truck tractors, and buses. The system describes, in detail, the test procedure, environment, instrumentation, and truck operating conditions for determining the maximum sound level. This measurement system is basically a certification type test. The test site and truck operational mode constraints negate its use as an on-highway noise-limit enforcement system. The SAE Recommended Practice includes the following specifications:

1. Instrumentation. Sound level meter, windscreen, and field calibrator meeting specified standards.
2. Calibration procedures.
3. Test site. Specified characteristics for actual measurement area plus the total surroundings within 100 to 200 feet of the measurement position.
4. Microphone location. Fifty feet from centerline of the truck path.
5. Measurement requirements. Fast response of the A-weighted network.

6. The operational mode of the vehicle. Gear ratio, speed, engine rpm, and acceleration sequence are specified.
7. Environmental conditions. No rain, winds less than 12 mph.
8. Ambient noise level. 10 dB or more below the noise to be measured.

Another typical measurement system, specified for a stationary test, is the pneumatic equipment noise test code applicable to the test of all types of pneumatic equipment under realistic operating conditions prevailing in industrial plants and at construction sites. This test was prepared through the cooperation of the Compressed Air and Gas Institute and the European Committee of Manufacturers of Compressed Air Equipment. The test code calls for:

1. Measurements to be made over a hard reflecting surface.
2. Operation to be under specified load.
3. Background noise to be at least 10 dB below that of the equipment under test.
4. A-weighted sound levels and octave band sound pressure levels to be measured at five or more specified locations.

These two specific measurement systems exemplify the rationale that must be followed in the design and establishment of test procedures to accurately characterize sources having noise levels heavily dependent on their interaction with the environment or the manner in which they are operated. It should be emphasized that in addition to precise measurement and calibration procedures, operational and environmental constraints incorporated into the standard measurement procedures are an absolute necessity. Such measurement systems exist for aircraft and surface transportation vehicles and, in a few cases, for specific machines; however, for the most part literally no measurement standards exist. This is especially true in the area of home appliances.

The availability of measurement standards does not imply that problems do not still exist. In some instances, there are several alternative measurement methods. When the results of different methods conflict, resolution is required. Also, it is not uncommon for test methods to be used under circumstances for which they were not designed.

7. Sound Transmission

Preceding sections have dealt with the measurement methodology for determining the noise levels associated with various sources, their impact on the acoustical environment, and their effect on man. This section will discuss the paths of noise transmission from source to receiver.

Increasing emphasis is being placed on site and highway planning to combat the ever-increasing encroachment of outdoor sounds into buildings. In this context, artificial barriers (walls, hills, other buildings) are being used to provide improved isolation from noise, particularly due to surface transportation. The exterior walls and roofs of houses and buildings near airports must exclude a substantial amount of noise from a variety of sources. There is a definite need for standardized methodology to measure and evaluate the effectiveness of (a) the noise isolation concepts of site and highway planning, and (b) the acoustical performance of exterior shells of buildings, in limiting the transmission of noise from outdoor sources. Whereas site planning is being utilized as a technique to combat the intrusion of outdoor noise into buildings, the following areas still need investigation:

- The orientation of buildings with respect to major highways, and airplane flight patterns, can have a substantial influence on the noise level at a particular point due to reflections from the buildings and the possible influence of the building arrangements on "focusing" the sound at certain locations. Procedures are needed for predicting, a priori, such effects.

- One building can serve as a sound barrier to shield another building from particular noise sources. Effectiveness depends on the ambient noise level, the noise level of the source, the desired acoustical environment, and the noise reduction achieved. This can be a complex problem and there is a need for standardized methodology to predict the noise isolation between the source and receiver locations so that alternative noise control procedures can be validly compared.

- Generally the reduction in noise levels by the erection of barriers, fences, etc., is not particularly effective unless the dimensions of the barrier are large compared with the wavelength of the sound being attenuated. Thus to effectively evaluate the transmission characteristics of barriers, the frequency spectrum of the source must be identified.

- The location of the barrier with respect to the source and the building is critical in determining the amount of attenuation. The need exists for the development of techniques to evaluate and compare the transmission characteristics of various barriers.

The acoustical environment within a building is also influenced by the other activities within the building--indoor noise sources. Building noise may be classified, according to its mode of transmission, as either airborne, structure-borne, or a combination of both. Airborne noise typically is transmitted along continuous air paths. Structure-borne noise typically originates from direct impacts, such as impulses produced by the dropping of objects on a floor, footsteps, door slamming, etc., or from direct mechanical contact between vibrating machinery and the building elements. Characterization of the sound transmission properties of building elements must consider both airborne and structure-borne noise.

Within a given room or enclosure, sound absorbing materials are frequently used to reduce the noise levels which arise due to a noise source within the same space. Laboratory techniques have been standardized for measuring the sound absorption of acoustical materials in a diffuse sound field. They yield results that are fairly representative of what would be obtained in field measurements. Sample mountings can be simulated to be identical to those encountered in actual practice. The severest limitation of this test method is the practical limitation of the sample size--it is difficult to predict the field performance of large areas of sound absorbing material. During the laboratory measurement, sound waves strike the sample at random angles of incidence. The sound fields encountered in large rooms are often not diffuse and there is a need to develop a standardized procedure to determine the effective absorption of acoustical materials for sound waves arriving from a specific direction.

Any meaningful investigation of the acoustical environment of buildings must include the measurement methodology associated with the performance of exterior and interior wall structures and floor/ceiling assemblies in the laboratory and in the field. Generally speaking, a partition, such as a wall or floor/ceiling assembly, which will provide adequate sound insulation in a given situation is one which will reduce the transmitted noise to a level below that of the normal background noise. The sound insulating property of a partition is usually characterized by the sound transmission loss, which is expressed as a function of frequency. The sound transmission loss is equal to the number of decibels by which sound power incident on one side of a partition is reduced in transmission through it.

The transmission of noise from one room to another room separated by an intervening partition wall may be either direct transmission through that wall, or indirect transmission through other walls, ceilings or floors common to both rooms. This noise transmission by indirect paths is known as flanking transmission, and often involves noise leaks occurring around floor, ceiling and partition edges, as well as around pipe and conduit penetrations. Thus in field measurements, it is frequently desired to know the total noise isolation, regardless of the transmission paths, between two spaces.

The American Society for Testing and Materials (ASTM) has adopted a Standard Recommended Practice for Laboratory Measurement of Airborne Sound Transmission Loss of Building Partitions (ASTM E90-70). This test method yields results for the sound insulating property of a partition element with a diffuse sound field on each side, thus providing a measure of the optimum inherent sound insulating capability of an interior partition. There is need for better specification of the appropriate techniques of mounting the test specimen.

Exterior walls and roofs are typically subject to free sound fields in which noise is incident from a specific direction. Standardized laboratory procedures are required for measurement of the sound isolation provided under such conditions.

There is also an ASTM Standard Recommended Practice for Field Measurement of Airborne Sound Insulation in Buildings (ASTM E336-71). There has been much less experience with this method than with the laboratory test method and considerable work appears indicated to validate and refine the procedures used--both for measurements of sound isolation between enclosed spaces and of isolation against noise of exterior origin. In addition, simplified tests proposed to be used by building code officials are in need of validation.

Impact noise is caused by an object striking against, or sliding on, a wall or floor structure, such as that produced by walking, falling objects, moving furniture, or slamming doors. In such cases the floor or wall is set into vibration by direct impact and sound is radiated from both sides. Impact noises constitute a serious problem because such noises generally are of high intensity and transient or impulsive in character. The problem is particularly acute in floors of light frame construction since they are easily set into vibration by impact excitation. Because of the inherent complexity of the generation and transmission of impact noise, the measurement and specification of the insulating properties of structures against such sounds, the determination of subjective reaction to these noises, and the development of impact sound insulation criteria for floor/ceiling structures have been highly controversial technical topics. Obviously, before specifying a requirement for impact sound insulation, a standard method for assessing the insulating properties of floor/ceiling structures is necessary.

A standard method of test for impact sound insulation has not yet been adopted in the U.S.A. although the ASTM is presently working toward that end. A method patterned after an earlier international (ISO R140) standard has been adopted as a proposed ASTM method, for information only. This proposed method differs from the ISO document in that it is more stringent in its methods of test and technique, it uses a different rating scheme, and it is for laboratory measurements only. This test method involves the operation of a "standard" tapping machine, described in the ISO document, which produces repeatable excitations of floor/ceiling structures; the resultant "impact sound pressure levels" produced in a subjacent reverberation room are measured. Many acousticians feel that the ISO tapping machine is not a suitable method for evaluating impact noise isolation. Some of the criticism of the efficacy of the tapping machine as an appropriate source of impact excitation is that it does not simulate that produced by walking, nor in fact, any other common indoor activity. Continued investigations leading toward improved measurement methodology for evaluation of impact noise isolation should be encouraged and pursued.

The noise generated and transmitted by heating and air conditioning systems is a significant problem in many buildings. Special treatments, such as sound absorbing duct liners and "sound traps," are used to minimize transfer of noise along ducts. The ASTM is currently working on a standard test procedure for measuring the sound isolation provided by such duct treatments.

A seriously neglected area of concern is the generation and transmission of plumbing noise. In addition to development of measurement methodology for generation of noise by plumbing fixtures, there is a need for test procedures concerning transmission of noise, of whatever origin, by plumbing systems.

8. Compilation of Standards

This section contains a compilation of existing standards related to acoustics. The listing includes the name of the organization or society issuing the standard, the complete title of the standard, and a brief summary of the scope and intent of the standard.

Complete standards can be purchased from the various organizations and societies whose addresses are given in Appendix E. The standards of the International Organization for Standardization (ISO) and the International Electrotechnical Commission (IEC) can be obtained from the American National Standards Institute (ANSI).

International Organization for Standardization

1. ISO Recommendation R31 Part VII. Quantities and Units of Acoustics (1965).

   This ISO Recommendation is part of a more comprehensive publication dealing with quantities and units in various fields of science and technology. It consists of a table listing the various quantities and units of acoustics. Preference is given to the International System of Units.

2. ISO Recommendation R131. Expression of the Physical and Subjective Magnitudes of Sound or Noise (1959).

   This ISO Recommendation states that the physical magnitude of sound or noise be expressed by a statement of sound pressure, power or intensity level, and the subjective magnitude as a loudness level in phons or loudness in sones. It also states the interrelationship between phons and sones.

3. ISO Recommendation R140. Field and Laboratory Measurements of Airborne and Impact Sound Transmission (1960).

   This ISO Recommendation defines methods of measuring the airborne sound insulation of walls, and the airborne and impact sound insulation of floors, both in the field and in the laboratory.

   The way in which the airborne and impact sound fields are generated, the frequency range of measurement and the characteristics of the necessary filters are described. Definitions are also given of the quantity measured in each case, and of the method of normalizing the results to make them comparable.

4. ISO Recommendation R226. Normal Equal-Loudness Contours for Pure Tones and Normal Threshold of Hearing Under Free Field Listening Conditions (1962).

   This ISO Recommendation specifies, for the frequency range 20 to 15000 Hz (c/s) and for the conditions stated below:

   a) The normal relations existing between sound pressure level and frequency for pure tones of equal loudness.

   b) Values for the normal threshold of hearing (normal binaural minimum audible field or MAF).

5. ISO Recommendation R266. Preferred Frequencies for Acoustical Measurements (1962).

This ISO Recommendation deals with the frequencies used for acoustical measurements. The variety of frequencies being used, prior to 1962, for acoustical measurements made comparison of results inconvenient. Some of the difficulties arose from the use of frequencies spaced at different intervals or of series starting from different reference frequencies. The purpose, therefore, of this ISO Recommendation is to refer all frequency-series to a single reference frequency, and to select other frequencies in such a way as to afford a maximum number of common frequencies in the various series.

For certain acoustical measurements, a constant frequency increment is a suitable spacing. More commonly, however, a constant percentage increment is adopted and the test frequencies then form a geometric series. The present ISO Recommendation deals with the geometric series and is not intended to apply to cases where a constant frequency increment, or other particular spacing, would be more suitable, or where there may be good reasons for the adoption or retention of other frequencies.

*6. ISO Recommendation R354. Measurement of Absorption Coefficients in a Reverberation Room (1963).

This ISO Recommendation describes how a reverberation room should be used to measure, under specified conditions, the sound absorption coefficients of acoustical materials used as wall or ceiling treatments, or the equivalent absorption area of separate objects, such as furniture, persons or space absorbers. The general principle is that the specimen is introduced into the room and the absorption added is computed from measurements of the reverberation time of the room (or the decay rate of the reverberant sound) before and after the introduction of the specimen.

It specifies certain features of the size and shape of the room, the size and disposition of the test specimen, the methods of measuring the reverberation time (or the decay rate of the reverberant sound) and of computing the results, the frequencies to be used and the manner in which the results should be stated.

7. ISO Recommendation R357 (Supplementary to R131). Expression of the Power and Intensity Levels of Sound or Noise (1963).

This ISO Recommendation defines the reference sound power and sound intensity.

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*The USA Member Body opposed the approval of this recommendation.

8. ISO Recommendation R362. Measurement of Noise Emitted by Vehicles (1964).

This ISO Recommendation describes methods of determining the noise emitted by motor vehicles, these being intended to meet the requirements of simplicity as far as is consistent with reproducibility of results and realism in the operating conditions of the vehicle.

It is based primarily on a test with vehicles in motion, the ISO reference test. It is generally recognized to be of primary importance that the measurements should relate to normal town driving conditions, thus including transmission noise, etc. Measurements should also relate to vehicle conditions which give the highest noise level consistent with normal driving and which lead to reproducible noise emission. Therefore, an acceleration test at full throttle from a stated running condition is specified.

Recognizing, however, that different practices were in existence before this recommendation, specifications of two other methods used are also given in the Appendix. These relate to:

a) a test with stationary vehicles (see Appendix A1) and

b) a test with vehicles in motion, under vehicle conditions which (in the case of certain vehicles) are different from those in the ISO reference test (see Appendix A2).

When either of these tests is used, the relation between the results and those obtained by the ISO reference test should be established for typical examples of the model concerned.

9. ISO Recommendation R389. Standard Reference Zero for the Calibration of Pure-Tone Audiometers (1964).

This ISO Recommendation specifies a standard reference zero for the scale of hearing threshold level applicable to pure-tone audiometers, which it is hoped will help to promote agreement and uniformity in the expression of hearing threshold level measurements throughout the world.

It states the information in a form suitable for direct application to calibration of audiometers, that is, in terms of the response of certain standard types of earphones measured on an artificial ear or coupler of stated type.

*10. ISO Recommendation R389, Addendum 1. Standard Reference Zero for the Calibration of Pure-Tone Audiometers. Additional Data in Conjunction with the 9-A Coupler (1970).

This Addendum to ISO Recommendation R389-1964 gives the corresponding reference equivalent threshold sound pressure levels for eleven audiometric earphones referred to a single type of coupler, namely, the National Bureau of Standards, Washington, D.C., USA, Type 9-A Coupler. Of these eleven earphones, five are those currently used as reference standards in a number of standardizing laboratories, and the remaining six are other types which have been used on commercial equipment and in audiometric laboratories.

11. ISO Recommendation R454. Relation Between Sound Pressure Levels of Narrow Bands of Noise in a Diffuse Field and in a Frontally-Incident Free Field for Equal Loudness (1965).

This ISO Recommendation specifies, for the frequency range 50 to 10,000 Hz (c/s), the difference (in decibels) between sound pressure levels for equal loudness of narrow bands of noise in diffuse and frontally-incident free-field conditions respectively, under the following conditions.

a) The sound pressure level is measured in the absence of the listener.

b) The listening is binaural.

c) The listeners are otologically normal persons in the age group from 18 to 25 years.

Note. An "otologically normal subject" is understood to be a person in a normal state of health who is free from all signs or symptons of ear disease and from wax in the ear canal.

d) The sound is a narrow band of noise of less than critical bandwidth.

12. ISO Recommendation R495. General Requirements for the Preparation of Test Codes for Measuring the Noise Emitted by Machines (1966).

This ISO Recommendation is concerned with the procedures to be followed in the objective measurement of the noise emitted by machines. These procedures are not necessarily applicable to noise of an impulsive character.

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* The USA Member Body opposed the approval of this recommendation.

The aim is to indicate the general principles by which specific test codes for noise measurements may be formulated. These general rules give different methods for measuring noise.

The specific codes for the various types of machines will have to select the most suitable method having regard to the size of the machine and its application. The codes themselves should contain all the necessary particulars to enable a result to be obtained with the required accuracy.

13. ISO Recommendation R507. Procedure for Describing Aircraft Noise Around an Airport (1970).

This ISO Recommendation provides a means for describing the total noise exposure on the ground around an airport produced by one or a number of aircraft, of the same type or different types, operating under any known set of conditions.

It specifies the five steps to be followed for this purpose:

1) A method of measurement of the noise produced on the ground by a given aircraft.

2) A method for determining from these data, values of tone-corrected perceived noise level including the effect of discrete tones when present.

3) A method for determining values of effective perceived noise level which, using the values obtained from (2) above, takes account of duration and regularity of spectrum of a single event.

4) A method for mapping contours around an airport for a given set of aircraft operations.

5) A method for determining a noise exposure index for a succession of events in a specified time interval.

It is outside the scope

a) to apply this ISO Recommendation directly to helicopters or vertical take-off flight vehicles;

b) to describe a method for computing from engine data the noise field produced on the ground by a future aircraft.

14. ISO Recommendation R512. Sound Signalling Devices on Motor Vehicles, Acoustic Standards and Technical Specifications (1966).

This ISO Recommendation deals with sound signalling devices

-- mounted on motor vehicles
-- functioning with an electrical current
-- designed for use outside built-up areas.

The aim of this ISO Recommendation is to specify their acoustic properties, such as spectral distribution of acoustic power and sound pressure level, and also their test conditions.

15. ISO Recommendation R532. Method for Calculating Loudness Level (1966).

This ISO Recommendation specifies two methods for calculating the loudness or loudness level of a complex sound, which differ not only in the method of analysis of the sound, but also in the principles of computation. The first, Method A, utilizes physical measurements obtained from spectrum analysis in terms of octave bands. The second, Method B, utilizes spectrum analysis in terms of one-third octave bands.

*16. ISO Recommendation R717. Rating of Sound Insulation for Dwellings (1968).

This ISO Recommendation describes a method of evaluating the airborne sound insulation and impact sound level for dwellings when the results of measurements made by the method described in ISO Recommendation R140 are available. Reference values are given with which the measured results should be compared by the method described.

A method is given to derive from this comparison a single index, in terms of which the sound insulation requirements can be defined.

*17. ISO Recommendation R1680. Test Code for the Measurement of the Airborne Noise Emitted by Rotating Electrical Machinery (1970).

This ISO Recommendation has been drafted in accordance with ISO Recommendation R495, and gives the detailed instructions for conducting and reporting tests on rotating electrical machines, to determine the airborne noise characteristics under steady state conditions.

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* The USA Member Body opposed the approval of this recommendation.

The main purpose of the test code is to give specific instructions so that the results obtained can always be compared.

The test code is divided into two parts:

Part I: Methods for usual tests based on sound level (A) measurements

Part II: Methods for special tests based on frequency band analysis measurements.

This test code for the measurement of noise applies to rotating electrical machines such as motors and generators of all sizes without limitation of output or voltage, when fitted with their normal auxiliaries.

18. ISO Recommendation R1761. Monitoring Aircraft Noise Around An Airport (1970).

This ISO Recommendation describes a measuring method for monitoring, on the ground, the noise produced by aircraft around an airport.

It specifies the measuring equipment to be used in order to measure noise levels created by aircraft in the operation of an airport. The noise levels measured are approximations to perceived noise level PNL.

In this ISO Recommendation monitoring is understood to be routine measurement of noise levels created by aircraft in the operation of an airport. Monitoring usually involves a large number of measurements per day, from which an immediate indication of the noise level is required.

Monitoring aircraft noise can be carried out either with mobile equipment, often using only a sound level meter, or with permanently installed equipment incorporating one or more microphones with amplifiers located at different positions in the field with a data transmission system linking the microphones to a central recording installation. This ISO Recommendation describes primarily the latter method, but specifications given in this ISO Recommendation should also be followed when using mobile equipment to the extent to which the specifications are relevant.

The sound levels measured according to this ISO Recommendation are approximations of perceived noise level in PNdB.

*19. ISO Recommendation R1996. Acoustics, Assessment of Noise With Respect to Community Response (1971).

The reduction, or limitation, of noise which causes annoyance is of increasing general importance. This ISO Recommendation suggests methods for measuring and rating noises in residential, industrial and traffic areas with respect to their interference with rest, working efficiency, social activities and tranquillity.

Besides noise there may be other factors in connection with sound production and radiation, for example mechanical vibrations, which also give rise to annoyance in particular situations and which make the assessment more complex. No general method exists at present to take account of these factors, but the application of numbers and corrections, other than those described, may be desirable in some cases.

The method described in this ISO Recommendation is considered suitable for predicting approximately the public reaction likely to be caused by noise, and may help authorities to set limits for noise levels.

This ISO Recommendation is intended as a guide to the measurement of acceptability of noise in communities. It specifies a method for the measurement of noise, the application of corrections to the measured levels (according to duration, spectrum character and peak factor), and a comparison of the corrected levels with a noise criterion which takes account of various environmental factors.

The method given for rating noises with respect to community response forms a basis on which limits for noises in various situations may be set by the competent authorities.

The method of rating involves the measurement of the A-weighted sound level in decibels (commonly called dB(A)).

Where corrective measures are required, a frequency analysis may be necessary. The resulting data may be compared with noise rating curves, for instance the NR-curves, in order to identify the intrusive frequency bands. This more elaborate procedure is described in an Appendix.

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[*] The USA Member Body opposed the approval of this recommendation.

20. ISO Recommendation R1999. Acoustics, Assessment of Occupational Noise Exposure for Hearing Conservation Purposes (1971).

Hearing impairment can be expressed, for many purposes, in terms of threshold shift at various frequencies. In most cases, however, the previous audiometric history is not available, so that prescriptions in terms of hearing level are necessary. Thus, for the retention of the faculty to understand conversational speech, a limit may be set to the permitted hearing level at frequencies of importance for the intelligibility of speech.

In this ISO Recommendation the recommendations and data are based primarily on the impairment criterion that hearing is considered impaired if the arithmetic average of the permanent threshold shifts for the three frequencies 500, 1000 and 2000 Hz is 25 dB or more.

The manner in which noise exposure is related to hearing impairment, for the purpose of this ISO Recommendation, is through the concept of "risk", defined below, this being an expression of the probability that exposed persons will acquire a specified degree of hearing impairment.

The levels and durations of the noises concerned are measured and an additive index is assigned to each. The sum of these indices is converted to a continuous noise level considered to be equally hazardous to hearing. A table is given to show the percentage of workers for which impairment of hearing according to the above impairment criterion will occur solely as a result of exposure to this noise during normal working time in periods of up to 45 years, the effects of age also being taken into account. Therefore, this ISO Recommendation provides a basis for the fixing of tolerable limits for noise exposure under working conditions by appropriate bodies.

It should be emphasized that if noise control methods are necessary in order to keep the exposure below fixed limits, more complicated measurements than those described in the main body of this ISO Recommendation may be necessary. An example of this is given in the Appendix.

This ISO Recommendation gives a practical relation between occupational noise exposure, expressed in terms of A-weighted sound level in dB (commonly called dB(A)) and duration within a normal working week (assumed to be 40 hours), and the percentage of the workers that may be expected to exhibit an increased threshold of hearing amounting to 25 dB or more averaged over the three frequencies 500, 1000 and 2000 Hz solely as a result of the noise exposure.

It is not applicable to impulsive noises consisting of noise of a duration less than 1 second or single high-level transients of a very short duration, for example, from gunfire.

International Electrotechnical Commission

1. IEC Recommendation, Publication 50 (08). International Electrotechnical Vocabulary, Electro-Acoustics (1960).

The purpose of this Recommendation is to list definitions that have been drawn up with the object of striking a correct balance between absolute precision and simplicity.

2. IEC Recommendation, Publication 118. Recommended Methods for Measurements of the Electro-Acoustical Characteristics of Hearing Aids (1959).

The purpose of these recommendations is to describe practicable and reproducible methods of determining certain physical performance characteristics of air-conduction hearing aids using electronic amplification and acoustically coupled to the eardrum by means of ear inserts, e.g., ear moulds or similar devices.

The acoustic test procedure is based on the free field technique, in which the hearing aid is placed in a plane progressive wave, with the earphone coupled to a standardized coupler.

Unless otherwise specified all measurements are carried out without using an ear insert (ear mould) which is normally to be regarded as incorporated in the coupler or the artificial ear employed.

The results obtained by the methods specified express the performance under the conditions of the test, but will not necessarily agree exactly with the performance of the hearing aid under practical conditions of use.

For this reason, the difference between practical and test conditions must be borne in mind in interpreting the test results.

3. IEC Recommendation, Publication 123. Recommendations for Sound Level Meters (1961).

The object of the present recommendation is to specify the characteristics of equipment to measure certain weighted sound pressure levels. The weighting applied to each sinusoidal component of the sound pressure is given as a function of frequency by three standard reference curves, called A, B, and C.

In practice, measurements may have to be made under very different conditions, ranging from the free field of a single source to a completely diffuse field.

In order to simplify the procedure for the calibration and checking of the apparatus, these recommendations are written primarily in terms of the free field response.

4. IEC Recommendation, Publication 126. IEC Reference Coupler for the Measurement of Hearing Aids Using Earphones Coupled to the Ear by Means of Ear Inserts (1961).

The purpose of this publication is to recommend a coupler for loading the earphone with a specified acoustic impedance when determining the physical performance characteristics, in the frequency range 200 to 5000 Hz (c/s), of air-conduction hearing aids using earphones coupled to the ear by means of ear inserts, e.g., ear moulds of similar devices. The coupler described is a development of an earlier 2 cm^3 coupler.

The use of this coupler does not allow the actual performance of a hearing aid on a person to be obtained; however, the I.E.C. recommends its use as a simple and ready means for the exchange of specifications and of physical data on hearing aids.

5. IEC Recommendation, Publication 177. Pure Tone Audiometers for General Diagnostic Purposes (1965).

The audiometer covered by this Recommendation is a device using pure tones designed for general diagnostic use and for determining the hearing threshold levels of individuals by:

a) monaural air-conduction earphone listening, and by

b) bone conduction.

The Recommendation does not purport to deal with all the features of audiometers, but specifies certain minimum requirements for a pure tone audiometer for general diagnostic use.

The purpose of this Recommendation is to ensure that tests of the threshold of hearing of a given individual on different audiometers, complying with the Recommendation, will give substantially the same results under comparable conditions and that the results obtained will present a good comparison between the threshold of hearing of the individual and the standard reference threshold of hearing.

This Recommendation applies primarily to audiometers giving discrete frequencies, but also applies to audiometers giving continuous frequency variation, as far as the provisions are relevant.

6. IEC Recommendation, Publication 178. Pure Tone Screening Audiometers (1965).

   The audiometer covered by this Recommendation is a device designed for screening purposes by monaural air-conduction earphone listening using pure tones.

   The Recommendation does not purport to deal with all features of screening audiometers, but specifies certain minimum requirements for a pure-tone audiometer for screening purposes.

   It is not implied that medical diagnosis can be based on screening procedures, but within its limitations a screening audiometer can be used to measure the hearing threshold levels of individuals.

7. IEC Recommendation, Publication 179. Precision Sound Level Meters (1965).

   This Recommendation applies to sound level meters for high precision apparatus for laboratory use, or for accurate measurements in which stable, high fidelity and high quality apparatus are required.

   This apparatus will be called: precision sound level meter.

   This Recommendation does not apply to apparatus for measuring discontinuous sounds or sounds of very short duration.

8. IEC Recommendation, Publication 200. Methods of Measurement for Loudspeakers (1966).

   This Recommendation applies only to single direct-radiator electrodynamic loudspeakers of the moving-coil type. If the terminals representing the moving coil are available, it is recommended that they be used, as this gives information about the unit in its most basic form. However, where other elements such as a transformer or a special network form part of the unit, or are prescribed in the manufacturer's specification to be used with the unit, it may be so tested provided that this is clearly stated when presenting the results. Provision is made for different acoustic loads by prescribing three types of mounting.

The object of this Recommendation is to specify, on the simplest possible basis, practical and uniform methods of measuring certain characteristics of loudspeakers, so that discussions between suppliers, users and testing authorities may be based on clearly expressed and reproducible results. The interpretation of the results and an assessment of actual performance are matters of the individual users' experience. This is because uniformity of measuring conditions demands a radical simplification of the acoustical environment, which is an important factor for determining loudspeaker performance; moreover, it should be remembered that the ultimate appeal is to human judgment. For these reasons, the objective measurements recommended need to be supplemented by subjective listening tests under the appropriate conditions if a final assessment is to be made.

*9. IEC Recommendation, Publication 225. Octave, Half-Octave and Third-Octave Band Filters Intended for the Analysis of Sounds and Vibrations (1966).

This Recommendation applies to band filters commonly known as octave, half-octave and third-octave band filters of the passive or active type, the latter including amplifier elements, e.g., tubes, valves and/or transistors.

It specifies the most important characteristics of these filters together with the corresponding tolerances.

The object of the Recommendation is to specify the characteristics of band-pass filters to be used in sound and vibration analysis for which octave and third-octave band-pass filters are preferred.

10. IEC Recommendation, Publication 268-1. Sound System Equipment Part 1: General (1968).

This Recommendation applies to sound systems of any kind, and to the parts of which they are composed or which are used as auxiliaries to such systems.

The Recommendation is confined to a description of the different characteristics and the relevant methods of measurement; it does not attempt to specify performance.

The purpose of this Recommendation is to facilitate the determination of the quality of audio-apparatus, the comparison of these types of apparatus and the determination of their proper practical applications, by listing the characteristics which are useful for their specification.

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*The United States National Committee cast a negative vote on this Publication.

11. IEC Recommendation, Publication 268-1A. First Supplement to Publication 268-1. Sound System Equipment. Part 1: General (1970).

This Recommendation deals with devices intended to give reverberation, time delay or frequency shift to electroacoustical signals. It covers devices of this kind as generally used for this purpose in sound recording, broadcasting and public address systems.

12. IEC Recommendation, Publication 268-2. Sound System Equipment. Part 2: Explanation of General Terms (1971).

The purpose of this Recommendation is to discuss and define the general terms applicable to sound system equipment.

13. IEC Recommendation, Publication 268-3. Sound System Equipment. Part 3: Sound System Amplifiers (1969).

This Recommendation applies to amplifiers which form the heart of a sound system, i.e., a system for the amplification and distribution of sound via input elements such as microphones and pick-ups and via output elements which are, in general, loudspeakers.

The amplifiers considered are valve amplifiers as well as transistor devices.

The purpose of this Publication is to give recommendations relative to the characteristics to be specified and the relevant measuring methods.

In general, the methods of measurement recommended are those which are seen to be the most directly related to the definitions. This does not exclude the use of other methods which will give equivalent results.

Rated conditions and normal working conditions as specified have been adopted as conditions for specifications and measurements.

14. IEC Recommendation, Publication 268-3A. First Supplement to Publication 268-3. Sound System Equipment. Part 3: Sound System Amplifiers (1970).

The purpose of this Recommendation is to include additonal information to Clause 16, Output Characteristics, of Publication 268-3 dealing with sound system amplifiers.

15. IEC Recommendation, Publication 268-14. Sound System Equipment. Part 14: Mechanical Design Features (1971).

This Recommendation applies to dimensional characteristics of single moving-coil (dynamic) loudspeakers of the direct radiator type.

The object of this Recommendation is to secure as great a measure of interchangeability as seems practicable, and to discourage unnecessary divergences.

16. IEC Recommendation, Publication 303. IEC Provisional Reference Coupler for the Calibration of Earphones Used in Audiometry (1970).

This Report describes an interim reference coupler for loading an earphone with a specified acoustic impedance, when calibrating audiometers, in the frequency range of 125 Hz to 8000 Hz.

The sound pressure developed by an earphone is not, in general, the same in the coupler as in a person's ear. However, the IEC recommends its use as a simple and ready means for the exchange of specifications on audiometers and for the calibration of earphones used in audiometry.

17. IEC Recommendation, Publication 318. An IEC Artificial Ear, of the Wide Band Type, for the Calibration of Earphones Used in Audiometry (1970).

This Recommendation relates to the specification of an artificial ear which covers the frequency band 20 Hz to 10000 Hz and is intended for calibrating supra-aural earphones applied to the ear without acoustical leakage. This device is not intended for the calibration of circumaural earphones.

The audiometric artificial ear is a device to permit calibration of earphones used in audiometry and comprises a microphone to measure the sound pressure and an acoustical network so constructed that the acoustical characteristics of the whole approximate to the acoustical characteristics of the mean external human ear.

American National Standards Institute

The American National Standards Institute, ANSI, was formed in October 1969. Prior to this date the official name of the organization was United States of America Standards Institute, USASI. USASI evolved from the American Standards Association, ASA, in August 1966. The standards presented in this document are listed under the organizational designation in effect at the time of their inception.

1. ASA S1.1-1960. American Standard Acoustical Terminology.

   The purpose of this Standard is to establish standard acoustical terminology.

2. ASA S1.2-1962. American Standard Method for the Physical Measurement of Sound.

   The purpose of this Standard is to establish methods for measuring and reporting the sound pressure levels and sound powers generated by a source of sound. A standard sound-level meter and standard octave-band filter set are considered minimum equipment. This standard is intended to serve as a basis for test codes and standards for specific types of sound sources. It applied primarily to airborne sound produced by apparatus which normally operates in air. These sounds must be non-impulsive and of sufficient duration to be within the dynamic measuring capabilities of the instruments used.

3. ANSI S1.4-1971. American National Standard Specifications for Sound Level Meters.

   The purpose of this Standard for Sound Level Meters and their calibration is to ensure maximum practical accuracy in any particular sound level meter, and to reduce to the lowest practical minimum any difference in corresponding readings among various makes and models of meters that meet the standard. The sound level meter is intended to be equally sensitive to sounds arriving at various angles, and to provide an accurate measurement of sound level with certain weightings for sounds within stated ranges and with an indicating instrument that has standardized characteristics. The basic calibration of the sound level meter is given in terms of a random-incidence acoustic field of known properties.

4. ASA S1.5-1963. American Standard Recommended Practices for Loudspeaker Measurements.

These Recommended Practices define terms associated with loudspeakers and their testing, recommend various methods of testing, and indicate preferred methods of presenting information regarding their characteristics. In these Practices, the tests recommended involve physical, steady-state measurements only. Work has been and is now being done on transient measurements of loudspeaker performance, but experience with these methods is still not sufficiently widespread to warrant their inclusion.

5. USAS S1.6-1967. USA Standard Preferred Frequencies and Band Numbers for Acoustical Measurements.

The variety of frequencies that were used prior to 1967 for acoustical measurements made comparison of results inconvenient. Some of the difficulties arose from use of different intervals or different starting frequencies for a series. The object of this Standard, therefore, is to refer all frequency-series to a single reference frequency and to select other frequencies in such a way as to afford a maximum number of frequencies common to the various series. The resulting simplification thus reduces to a minimum the number of frequencies at which acoustical data need to be tabulated. For certain acoustical measurements a constant-frequency increment is a suitable spacing. More commonly, however, a constant-percentage increment is adopted and the test frequencies then form a geometric series. This standard deals with the geometric series.

6. ANSI S1.8-1969. American National Standard Preferred Reference Quantities for Acoustical Levels.

This Standard is concerned with the reference quantities and the definitions of some levels for acoustics, electroacoustics, and mechanical vibrations. It applies to oscillatory quantities. The use of levels is not made mandatory by this standard. It simply provides standard reference quantities for use when, and if, levels are employed for reasons beyond the scope of the standard. The present standard is intended to encourage uniformity of practice by specifying a definition for a level likely to be employed in acoustics. The purpose of this standard is to provide a preferred reference quantity of convenient magnitude for a given kind of acoustical level.

7. ASA S1.10-1966. American Standard Method for the Calibration of Microphones.

In this Standard, methods are described for performing absolute and comparison calibrations of laboratory standard microphones specified in USASI S1.12-1967. Absolute calibration is based upon the reciprocity principle. Techniques for performing pressure (coupler), free-field, and random-field calibrations are described, including experimental procedures. The free-field and random-field calibration techniques may also be used for calibrating microphones not described in USASI S1.12-1967.

8. ASA S1.11-1966. American Standard Specification for Octave, Half-Octave, and Third-Octave Band Filter Sets.

The purpose of this Standard for filter sets is to specify particular bandwidths and characteristics which may be used to ensure that all analyses of noise will be consistent within known tolerances when made with similar filter sets meeting these specifications. The standard for filter sets is suited to the requirements for analyzing, as a function of frequency, a broadband electrical signal. For acoustical measurements an electro-acoustic-transducer and amplifier are employed to convert the acoustical signal to be analyzed into the required electrical signal.

9. USAS S1.12-1967. USA Standard Specifications for Laboratory Standard Microphones.

This Standard describes types of laboratory microphones that are suitable for calibration by an absolute method such as the reciprocity technique described in USA Standard Method for the Calibration of Microphones, S1.10-1966. These microphones are intended for use as acoustical measurement standards either in a free-field or in conjunction with a variety of devices such as artificial voices and couplers for calibrating earphones or microphones.

10. ANSI S1.13-1971. American National Standard Methods for the Measurement of Sound Pressure Levels.

The purpose of this Standard is to establish uniform guidelines for measuring and reporting sound levels and sound pressure levels observed under different environmental conditions. This standard is applicable to the many different types of sound pressure level measurements commonly encountered in practice. This standard is intended to assist in the preparation of test codes for: (1) determining compliance with a specification, ordinance, or acoustical criterion, and (2) obtaining information to assess the effects of noise on people or equipment.

11. ASA S3.1-1960. American Standard Criteria for Background Noise in Audiometer Rooms.

This Standard specifies the maximum ambient sound pressure levels in an audiometer room that will produce negligible masking of tones presented at the normal threshold pressures specified in USASI S3.6-1969.

12. ASA S3.2-1960. American Standard Method for Measurement of Monosyllabic Word Intelligibility.

This Standard describes the procedures to be followed in conducting intelligibility tests which employ monosyllabic word lists. The purpose of this standard is: (1) to specify the speech material and the methods to be used in these tests; and (2) to note the variables to be controlled during the measurement and to be evaluated in the report.

13. ASA S3.3-1960. American Standard Methods for Measurement of Electroacoustical Characteristics of Hearing Aids.

The purpose of this Standard is to describe practicable and reproducible methods of determining certain physical performance characteristics of air-conduction hearing aids that use electronic amplification and acoustic coupling to the ear canal by means of ear inserts, e.g., ear molds or similar devices. This Standard does not apply when automatic gain control is in use.

The acoustic test procedure is based on the free-field technique, in which the hearing aid is placed in a plane progressive wave with the earphone coupled to a standardized coupler.

The results obtained by the methods specified express the performance under the conditions of the test, but will not necessarily agree exactly with the performance of the hearing aid under practical conditions of use.

14. USAS S3.4-1968. USA Standard Procedure for the Computation of Loudness of Noise.

This Standard specifies a procedure for calculating the loudness experienced by a typical listener under the following conditions:

1. Diffuse Field. The sound is assumed to reach the listener's ears from essentially all directions. This condition is approximated in an ordinary room.

2. Spectrum. The procedure is designed specifically for noises with broad-band spectra. Errors may arise if it is applied to noises with sharp line spectral components, e.g., fan-blade noise.

3. Steady State. The procedure is designed for noises that are steady state rather than intermittent. Application to certain types of intermittent sounds, e.g., impact sounds and speech, may lead to discrepancies between measured and calculated loudness levels. The magnitude of the discrepancy will be related to the dynamic characteristics of the sound level meter used to determine the sound pressure levels.

15. ANSI S3.5-1969. American National Standard Methods for the Calculation of the Articulation Index.

Methods have been developed for computing a physical measure that is highly correlated with the intelligibility of speech as evaluated by speech perception tests administered to a given group of talkers and listeners. This measure is called the Articulation Index, or AI. The AI is a weighted fraction representing, for a given speech channel and noise condition, the effective proportion of the normal speech signal that is available to a listener for conveying speech intelligibility. AI is computed from acoustical measurements or estimates of the speech spectrum and of the effective masking spectrum of any noise which may be present along with the speech at the ear of a listener.

The method described in this Standard is designed for and has been principally validated against intelligibility tests involving adult male talkers. The method cannot, therefore, be assumed to apply to situations involving female talkers or children.

16. ANSI S3.6-1969. American National Standard Specifications for Audiometers.

The audiometers covered by this Specification are devices designed for use in determining the hearing threshold level of an individual, in comparison with a chosen standard reference threshold level, primarily for the purpose of identification of hearing deficiencies of the individual.

The purpose of this Specification is to insure that tests of the hearing of a given individual ear on different audiometers of a given class complying with this specification shall give substantially the same results under comparable conditions, and that the results obtained shall represent a true comparison between the hearing threshold level of the individual ear and the standard reference threshold level.

17. USAS S3.8-1967. USA Standard Method of Expressing Hearing Aid Performance.

The purpose of this Standard is to provide a uniform method of numerically and graphically expressing certain fundamental performance characteristics of hearing aids in a simple manner, so that those using such data can be assured of their meaning.

All quantities to be specified in this Standard shall be based on measurements made in accordance with USA Standard Methods for Measurement of the Electroacoustical Characteristics of Hearing Aids, S3.3-1960.

18. ANSI S5.1-1971. American National Standards Test Code for the Measurement of Sound From Pneumatic Equipment.

This Standard applies to compressors and pneumatic equipment and specifies procedures and operating conditions acceptable and expedient for use by non-specialists as well as by acoustic engineers.

19. ASA Y10.11-1953. American Standard Letter Symbols for Acoustics.

This Standard comprises letter symbols for use in acoustics.

20. ASA Z24.9-1949. American Standard Method for the Coupler Calibration of Earphones.

The purpose of this Standard is to describe a practical and reproducible method of evaluating the performance characteristics of an earphone by means of physical measurements of the earphone in conjunction with a standard terminating volume known as the "coupler".

The method is adequate for controlling the characteristics over the frequency range most useful for speech, i.e., 300 to 5,000 H$_z$.

This Standard specifies a number of couplers, each of which is suitable for a certain type of earphone. No one of these couplers is suitable for all of the different types. Test laboratories are expected to select the coupler which is most suitable for each particular instrument in order that their results may be comparable with those obtained for other instruments of the same general type but of different manufacture.

21. ASA Z24.22-1957. American Standard Method for the Measurement of the Real-Ear Attenuation of Ear Protectors at Threshold.

This Standard specifies the physical requirements, psychophysical procedures, and means of reporting results for measuring the real-ear attenuation at threshold of any wearable device that is designed to protect the auditory system against excessive sound.

Tests described in this Standard are designed to measure only real-ear attenuation at threshold. The quality of an ear protector cannot be decided on the basis of such tests alone; other factors must be taken into account, such as toxicity of the material used, sanitation, comfort in use, and the ability to maintain effective attenuation in use.

Tests described in this Standard for real-ear attenuation at threshold are meant to be applied when the effectiveness of a completely developed ear protector is to be ascertained. There are other, quicker and less involved, procedures not described in this Standard that may be used by manufacturers and others in the development of new ear protector designs or materials. Such methods include loudness balance techniques and physical tests with an artificial head.

American Society for Testing and Materials

1. ASTM Designation: C384-58. Standard Method of Test for Impedance and Absorption of Acoustical Materials by the Tube Method.

   This Method of Test is limited to the use of apparatus consisting of a tube of uniform cross-section and fixed length, excited by a single tone of selectable frequency, in which the standing wave pattern in front of a specimen upon which plane waves impinge at normal incidence is explored by means of a moving probe tube or microphone. This tube method provides absolute measurement of the normal incidence sound absorption coefficient and the specific normal acoustic impedance of a material. Normal incidence coefficients, as measured by this method, are considerably lower than random incidence values, which more closely represent the performance of the material in a room; and there is no simple, unique relation between the two values. Means of estimating random incidence values from the measured normal incidence data from the measured normal incidence data are given in Appendix I.

2. ASTM Designation: C423-66. Standard Method of Test for Sound Absorption of Acoustical Materials in Reverberation Rooms.

   This Method covers the measurement of the sound absorption of acoustical materials in a diffuse sound field. When a material is in the form of an extended plane surface, such as an acoustical ceiling or wall treatment, the results shall be given as sound absorption coefficients. When the materials are separate objects, such as theater chairs or unit sound absorbers, the results shall be given in sabins per unit with a description of the number and spacing of the units.

3. ASTM Designation: C634-69. Standard Definitions of Terms Relating to Acoustical Tests of Building Constructions and Materials.

   This Standard lists the terms commonly associated with the acoustical tests of buildings. In some of the entries, those that are measures of physical quantities, the associated symbol dimensions and units are given.

4. ASTM Designation: E90-70. Standard Recommended Practice for Laboratory Measurement of Airborne Sound Transmission Loss of Building Partitions.

   This Recommended Practice covers the laboratory measurement of airborne sound transmission loss of building partitions such as walls of all kinds, floor-ceiling assemblies, doors, and other space-dividing elements. The sound transmission loss is defined in terms of a diffuse incident sound field, and this is intrinsic to the test procedure. The results are most directly applicable to similar sound fields, but provide a useful general measure of performance of the variety of sound fields to which a partition may typically be exposed.

5. ASTM Designation: E336-71. Standard Recommended Practice for Measurement of Airborne Sound Insulation in Buildings.

This Recommended Practice establishes uniform procedures for the determination of field transmission loss, that is, the airborne sound insulation provided by a partition already installed in a building. It also establishes, in Appendix A1, a standard method for the measurement of the noise reduction between two rooms in a building, that is, the difference in average sound pressure levels in the rooms on opposite sides of the test partition. Where the test structure is a complete enclosure out-of-doors, neither the field transmission loss nor the noise reduction is appropriate; instead, a method is established for determining the insertion loss, also in Appendix A1. This Recommended Practice gives measurement procedures for determining the field transmission loss in nearly all cases that may be encountered in the field; no limitation to room-to-room transmission is intended. Thus, several different test procedures are given, each suited to a specific type of measurement situation; the appropriate measurement procedure must be selected for each field test according to the type of situation which that particular case most closely resembles.

6. ASTM Designation: E413-70T. Tenative Classification for Determination of Sound Transmission Class.

The purpose of this Classification is to provide a single-figure rating that can be used for comparing partitions for general building design purposes. The rating is designed to correlate with subjective impressions of the sound insulation provided against the sounds of speech, radio, television, music and similar sources of noise in offices and dwellings. Excluded from the scope of this classification system are applications involving noise spectra that differ markedly from those described above. Thus excluded, for example, would be the noises produced by most machinery, certain industrial processes, bowling alleys, power transformers, and the like. A particular exclusion would be the exterior walls of buildings, for which noise problems are most likely to involve motor vehicles or aircraft. In all such problems it is best to use the detailed sound transmission loss values, in conjunction with actual spectra of intrusive and ambient noise.

*7. ASTM Proposed Method (RM 14-3). Proposed Method of Steady-State Determination of Changes in Sound Absorption of a Room. (1966)

This Method is introduced , for information only, primarily for use in studying the utility of the steady-state technique, as an adjunct to the procedures given in ASTM Recommended Practice E90-70, for Laboratory Measurement of Airborne Sound Transmission Loss of Building Partitions.

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* This Method is being dropped from the Book of Standards.

8. ASTM Proposed Method (RM-14-4). Proposed Method of Laboratory Measurement of Impact Sound Transmission Through Floor Ceiling Assemblies Using the Tapping Machine (1971).

This method covers a laboratory method of measuring impact sound transmission of floor-ceiling assemblies, wherein it is assumed that the test specimen constitutes the primary sound transmission path into a receiving room located directly below and in which there exists a diffuse sound field. Measurements may be conducted on floor-ceiling assemblies of all kinds, including those with floating-floor or suspended ceiling elements, or both, and floor-ceiling assemblies surfaced with with any type of floor-surfacing or floor-covering materials. This method further prescribes: a uniform method of reporting laboratory test data, and a single-figure classification rating, "Impact Insulation Class, IIC" that can be used by architects, builders, and specification and code authorities for acoustical design purposes in building construction. Details regarding its derivation and significance are given in Appendix A1.

Society of Automotive Engineers

1. SAE Recommended Practice J184. Qualifying a Sound Data Acquisition System. (1970)

Various SAE vehicle noise standards require use of a sound level meter which meets the requirements of International Electrotechnical Commission (IEC) Publication 179, Precision Sound Level Meters, and American National Standard (ANSI) S1.4-1961, Sound Level Meters. The purpose of this Recommended Practice is to provide a procedure for determining if an acoustical data acquisition system has performance equivalent to such a meter.

2. SAE Recommended Practice J192. Exterior Sound Level for Snowmobiles. (1970)

This SAE Recommended Practice establishes the maximum exterior sound level for snowmobiles and describes the test procedure, environment, and instrumentation for determining this sound level.

3. SAE Recommended Practice J336. Sound Level for Truck Cab Interior. (1968)

This SAE Recommended Practice suggests design criteria for maximum truck cab interior sound levels and describes the equipment and procedure for determining this sound level. This Practice applies to new motor trucks and truck-tractors and does not include construction and industrial machinery as outlined in SAE J919.

4. SAE Recommended Practice J366. Exterior Sound Level for Heavy Trucks and Buses. (1969)

   This SAE Recommended Practice establishes the maximum exterior sound level for highway motor trucks, truck-tractors, and buses, and describes the test procedure, environment, and instrumentation for determining the maximum sound level.

   The sound level produced by trucks and buses over 6000 lb. gvw shall not exceed 88 dB on an A-weighted network at 50 ft when measured in accordance with the procedure described.

5. SAE Standard J377. Performance of Vehicle Traffic Horns. (1969)

   This SAE Standard establishes the minimum operational life cycles, corrosion resistance, and sound level output for traffic horns (electric) on new automotive highway vehicles. Test equipment, environment, and procedures are specified.

6. SAE Standard J671. Sound Deadeners and Underbody Coatings. (1958)

   The materials classified under this Specification are:

   1. Mastic sound deadeners used to reduce the sound emanating from metal panels.

   2. Mastic underbody coatings used to give protection and some sound deadening to motor vehicle underbodies, fenders, and other parts.

7. SAE Standard J672a. Exterior Loudness Evaluation of Heavy Trucks and Buses. (1970)

   This SAE Standard establishes the design criteria for loudness of highway trucks, buses, and truck-tractors exceeding 6000 lb gvw; it describes the equipment, test environment, and procedure for determining the loudness. In this Method, the sound level is recorded on a tape recorder at a test site as the truck passes by under load. The sound thus recorded is played back through a set of octave bandpass filters. The peak band pressure level readings are converted to sones by established relationships. The sones are then totaled to obtain a single loudness reading for the vehicle.

8. SAE Recommended Practice J919. Measurement of Sound Level at Operator Station. (1966)

This SAE Recommended Practice sets forth the equipment and procedure to be used in measuring sound levels at the operator station.

The scope of construction and industrial machinery encompasses only mobile equipment, powered by internal combustion engines, and generally utilized outside factory and building areas, such as crawler tractors, dozers, loaders, power shovels and cranes, motor graders, paving machines, off-highway trucks, ditchers, trenchers, compactors, scrapers, and wagons.

9. SAE Recommended Practice J919a. Sound Level Measurements at the Operator Station for Agricultural and Construction Equipment. (1971)

This SAE Recommended Practice sets forth the instrumentation and procedure to be used in measuring sound levels at the operator station for agricultural and construction equipment, including mobile outdoor industrial equipment.

10. SAE Standard J952b. Sound Levels for Engine Powered Equipment. (1969)

This SAE Standard establishes maximum sound levels for engine powered equipment and describes the test procedure, environment, and instrumentation for determining these sound levels. It does not include machinery designed for operation on highways or within factories and building areas.

11. SAE Standard J986a. Sound Level for Passenger Cars and Light Trucks. (1970)

This SAE Standard establishes the maximum sound level for passenger cars and light trucks and describes the test procedure, environment, and instrumentation for determining this sound level.

12. SAE Recommended Practice J994. Criteria for Backup Alarm Devices. (1967)

This SAE Recommended Practice establishes the sound levels for backup alarm devices when used on construction and industrial machinery. It also establishes the equipment and procedure to be used when making such measurements.

The scope of construction and industrial machinery encompasses only mobile equipment, powered by internal combustion engines and generally utilized outside factory and building areas, such as crawler tractors, dozers, loaders, power shovels and cranes, motor graders, paving machines, off-highway trucks, ditchers, trenchers, compactors, scrapers, and wagons.

13. SAE Aerospace Recommended Practice ARP 796. Measurement of Aircraft Exterior Noise in the Field. (1965)

The purpose of this Recommended Practice is to define measurement techniques and equipment for acquisition and reduction of basic data on aircraft exterior noise. It is not its purpose to propose use of these techniques or this equipment for research or monitoring-type tests.

14. SAE Aerospace Recommended Practice ARP 865A. Definitions and Procedures for Computing the Perceived Noise Level of Aircraft Noise. (1969)

This SAE Recommended Practice gives definitions and procedures for computing the perceived noise level of aircraft noise. The perceived noise level is a single number rating of the noise based upon objective acoustic measurements which is related to the relative subjective response to the noise. The perceived noise level, as defined in this document, is based only on the noise spectra measured in octave or one-third octave bands of frequency. As such, it is most accurate in rating broadband sounds of similar time duration which do not contain strong discrete frequency components.

When additional factors such as the duration and the presence of discrete frequency components are to be taken into account, the effective perceived noise level (EPNL) may be a preferred measure.

15. SAE Aerospace Recommended Practice ARP 866. Standard Values of Absorption as a Function of Temperature and Humidity for Use in Evaluating Aircraft Flyover Noise. (1964)

This report describes a method by which values can be obtained for the absorption of sound in air over a wide range of temperature and humidity conditions. Although it was developed primarily for use in evaluating aircraft fly-over noise measurements, the information should be applicable to other noise problems as well.

There are a number of factors which influence the propagation of aircraft noise from an aircraft flying overhead to a point on the ground. The purpose here, however, is to consider only the classical and molecular absorption of sound energy by the atmosphere. It is felt that spherical divergence, scattering, refraction, and other effects should be treated separately.

16. SAE Aerospace Recommended Practice ARP 1080. Frequency Weighting Network for Approximation of Perceived Noise Level for Aircraft Noise. (1969)

This Aerospace Recommended Practice specifies a frequency weighting network which may be used for the approximation of Perceived Noise Level.

There has been an increasing desire for the definition of a frequency weighting network which could be incorporated into direct reading and other instruments for the approximate measure of the Perceived Noise Level of an aircraft flyover. The 40 Noy contour of ARP 865A, Definitions and Procedures for Computing the Perceived Noise Level of Aircraft Noise, has been selected as the most representative for this purpose.

17. SAE Aerospace Information Report AIR 817. A Technique for Narrow Band Analysis of a Transient (1967).

This SAE Report describes a technique for analyzing a transient signal of short duration. The standard method of analyzing tape recorded signals of only a few seconds duration is the "loop method". The magnetic tape is cut and spliced to form an endless loop, and the loop is replayed with the aid of a tensioning device. Difficulty arises with transient signals when the length of tape required to make a loop covers a time over which there is a considerable variation. The principle of the system described is that of expanding the timebase of the signal to a point at which there is a length of tape sufficient to make a loop across which the signal is essentially constant. Although the method is one which has been used specifically for the analysis of aircraft flyover noise, it could equally well apply to other transient signals.

18. SAE Aerospace Information Report AIR 852. Methods of Comparing Aircraft Takeoff and Approach Noise. (1965)

It is the purpose of this Information Report to describe a method for rating complex aircraft noises or noise flyover cycles which cannot be handled by means of mathematical formulae by comparing them with simpler aircraft noises or noise flyover cycles which can be handled by mathematical formulae.

The report describes the need for an objective means for rating aircraft noise and recommends areas which should be investigated.

19. SAE Aerospace Information Report AIR 876. Jet Noise Prediction. (1965)

This SAE Report provides calculation procedures for predicting maximum fly-by noise and maximum static ground operation noise from jet aircraft. Three types of engine exhausts are considered:

1. Turbojet with standard circular nozzle.
2. Turbojet with nonstandard nozzle.
3. Turbofan or bypass engine with (a) unmixed exhausts or (b) completely mixed exhausts.

Noise predictions are in terms of octave-band sound pressure levels of maximum air-to-ground fly-by noise or of maximum ground-to-ground side-line noise. These levels may be converted to an over-all sound pressure level or to a subjective rating such as Perceived Noise Level.

20. SAE Aerospace Information Report AIR 902. Determination of Minimum Distance from Ground Observer to Aircraft for Acoustic Tests. (1966)

This SAE Report describes a photographic technique for determining minimum observer-to-aircraft distance during acoustic "fly-over" tests. Possible sources of error are discussed, and it is shown that with ordinary care results are sufficiently accurate to require no correction.

21. SAE Aerospace Information Report AIR 923. Method for Calculating the Attenuation of Aircraft Ground to Ground Noise Propagation During Takeoff and Landing. (1966)

The purpose of this SAE Report is to provide a standard method for predicting the propagation of noise over open terrain from (a) an airplane on the ground to other locations on the ground and from (b) an airplane at low altitude, - i.e., where ground effects exist - to locations on the ground at distances which are great compared with the airplane altitude.

This report provides extensive information on what has been called the "shadow effect", i.e., attenuation resulting from temperature and wind gradients near the ground. This effect is called "extra ground attenuation" because it is in addition to the inverse square attenuation and the extra air attenuation.

22. SAE Aerospace Information Report AIR 1115. Evaluation of Headphones for Demonstration of Aircraft Noise. (1969)

The purpose of this SAE Report is to present the results of an engineering evaluation of commercially available headphones from the standpoints of frequency range, flatness of response and tolerances, and dynamic range.

Institute of Electrical and Electronics Engineers

1. IEEE No. 85. Test Procedure for Airborne Noise Measurements on Rotating Electric Machinery. (1965)

This Test Procedure covers instructions for conducting and reporting tests on rotating electric machines of all sizes to determine the airborne noise characteristics under steady-state conditions. The purpose of this Test Procedure is to outline practical techniques and procedures which can be followed for the uniform determination of the noise produced by a single machine in the normal audible frequency range. It is not intended that the Test Procedure cover all possible tests. The Test Procedure shall not be interpreted as requiring the making of any or all of the tests described in any given transaction.

2. IEEE No. 151. Standard Definitions of Terms for Audio and Electroacoustics. (1965)

This Standard lists definitions of terms for which it was felt a need exists for establishment of precise and concise meanings.

The definitions included in this Standard all refer specifically to the use of the terms in audio techniques.

3. IEEE No. 258. Test Procedure for Close-Talking Pressure-Type Microphones. (1965)

This document describes a practical and reproducible method of evaluating the performance characteristics of a close-talking microphone by means of quantitative measurements of the microphone characteristics using a standard artificial voice. Terms associated with microphones and their testing are defined. Test procedures, methods of presentation of data, and a standard artificial voice are specified. The tests described in this document involve physical, steady-state measurements only. The data obtained should be sufficient to enable an evaluation of quality and performance of a given microphone in a speech communication system. However, since it is sometimes desirable to obtain a subjective evaluation of a microphone, a procedure for a qualitative performance test is described in Appendix I.

Several sections of the document specify experimental limits to account for the effect of the test procedures on the accuracy of the data. These limits have been chosen so that results within the range of normal engineering accuracy will be obtained.

4. IEEE No. 297. IEEE Recommended Practice for Speech Quality Measurements (1969).

The IEEE Subcommittee on Subjective Measurements, charged with writing an engineering practice for the measurement of speech quality, concluded that a single method should not now be recommended. This Recommended Practice is concerned only with preference measurements for which three methods are tentatively outlined. These are the Isopreference Method, the Relative Preference Method, and the Category-Judgment Method.

American Society of Heating, Refrigerating and Air-Conditioning Engineers

1. ASHRAE Standard 36-62. Measurement of Sound Power Radiated from Heating, Refrigerating and Air-Conditioning Equipment.

This Standard is intended to provide a means for determining the character and amount of the sound produced by air conditioning, refrigerating and heating equipment. It should provide a basis for comparison among the available equipment and also for estimating the sound pressure level to be expected from the equipment in a given space.

If this Standard is to fulfill its purpose and make possible the proper comparison of ratings reported by different manufacturers, a relatively high degree of absolute accuracy is necessary. Such absolute accuracy is difficult to obtain by means of instruments and techniques available at this time (1962). To minimize this difficulty, this Standard uses a "reference sound source" calibrated directly in sound power output, thus permitting the determination of the sound power output of the equipment by direct comparison with the reference sound source.

2. ASHRAE Standard 36A-63. Method of Determining Sound Power Levels of Room Air Conditioners and Other Ductless, Through-The-Wall Equipment.

This Standard, while complete in itself, follows the provisions of Standard 36-62, wherever possible.

The purpose of this Standard is to establish a method of determining the sound power levels of room air conditioners and other ductless wall or ceiling-mounted heating, ventilating, and air-conditioning equipment which radiate sound directly to both the conditioned space and the outdoors. The sound power radiated to the conditioned space and that radiated to the outdoors are to be determined separately and by one-third octave band increments.

The method given in this Standard measures only airborne sound radiated from the equipment itself. It is recognized that additional low frequency sound may be radiated from the structure in which the equipment is mounted as a result of vibration transmitted from the equipment. The magnitude of this additional sound will depend upon the characteristics of the particular structure involved and this is a function of the equipment application.

Finally, it should be noted that this Standard does not cover the measurement of transient sounds which may occur, for example, during the starting or stopping of equipment nor the measurement of the directivity patterns of the sound radiated from the equipment on test. For special situations where these characteristics may be significant, other sound measurement methods must be employed.

3. ASHRAE Standard 36B-63. Method of Testing for Rating the Acoustic Performance of Air Control and Terminal Devices and Similar Equipment.

This Standard, while complete in itself, follows the provisions of the generic ASHRAE Standard 36-62 prepared by that committee wherever possible. Modifications have been made, however, to make this Standard specifically applicable to air control and terminal devices used in air-conditioning, heating and ventilating systems.

The purpose of this Standard is to present, in a single document, all those techniques, facilities and procedures required for the determination of sound power generation and attenuation of one particular group of air conditioning, heating and ventilating system components: Air Control and Terminal devices, which are generally duct-connected to a central air moving system.

Air-Conditioning and Refrigeration Institute

1. ARI Standard 270. Standard for Sound Rating of Outdoor Unitary Equipment (1967).

ARI has produced this Standard in order to provide the industry and the public with a procedure for rating and evaluating the sound levels of outdoor unitary equipment. The rating numbers may be used to predict expected sound pressure levels in a specific acoustical environment at a given distance. A recommended procedure for accomplishing this will be described in a related ARI application standard.

In this Standard, the rating of equipment, as obtained at specified Standard Operating Conditions, is in the form of single numbers, designated as ARI Standard Sound Rating Numbers.

For a specific model of outdoor unitary equipment, an ARI Standard Sound Rating Number is developed from basic acoustic measurements made as prescribed in ASHRAE Standards 36-62 or 36A-63, as applicable. These measured one-third octave band power levels are weighted to adjust for psychoacoustic sensitivity to frequency distribution and any discrete tones which may be present and then are converted to an ARI Standard Sound Rating Number.

2. ARI Standard 275. Standard for Application of Sound Rated Outdoor Unitary Equipment (1969).

This standard provides a method of predicting the sound level resulting from the operation of outdoor sections of unitary air-conditioning and heat pump equipment. A simple step-by-step procedure is given which uses a sound rating number for the equipment, and the distance to the point at which equipment noise is to be predicted. The nature of the surroundings and of the installation is also taken into account.

The sound rating number is adjusted for these installation factors to establish a sound level number (SLN) which is used in an alignment chart to predict, for a specific location, a tone-corrected sound level which is intended to be a predictor of annoyance due to the sound. This annoyance level (ANL) may be experimentally checked in a precise manner by applying the calculations specified in Appendix A to one-third octave band sound pressure levels measured at the point of question. It may be approximately checked (normally within ± 4 dB) by a measurement of dBA. If desired, the NC level of the sound may also be estimated from the alignment chart. The accuracy of the prediction is dependent upon other application variables; i.e., the directivity of the sound from the unit and, to some degree, the spectrum of the sound from the unit.

Examples are used to clarify the procedure and recommended practices are presented to guide the acoustic considerations of air-conditioning equipment installations.

This Standard shall not be used for determining the sound rating number of outdoor unitary equipment.

3. ARI Standard 443. Standard for Sound Rating of Room Fan-Coil Air-Conditioners (1970).

ARI has produced this standard to fulfill a growing need for a reliable method of sound rating room fan-coil air-conditioners.

This Method of rating is based upon tests conducted in accordance with ASHRAE Standard 36-62, which gives test results for sound power levels. The acoustic output can best be defined by sound power levels, since these quantities are independent of the many environments in which the equipment may be used. Sound power levels may be used to predict the sound pressure levels that will result in a space of known acoustical characteristics.

It is recognized that room fan-coil air-conditioners and most other air-conditioning equipment produce complex sound spectra which may not be suitably rated from broad band measurements alone. The annoyance of pure tones, for example, is not reflected in octave band measurements. Consequently, this Standard requires measurements by one-third octave bands and applies subjective corrections based on extensive research in order to arrive at meaningful ratings.

4. ARI Standard 446. Standards for Sound Rating of Room Air-Induction Units (1968).

ARI has produced this Standard to fulfill a growing need for a reliable method of sound rating room air-induction units.

The relationship between this Standard and ASHRAE 36B-63 is analogous to the relationship between ARI 443 and ASHRAE 36-62.

It should also be recognized that the sound power levels of room air-induction units will vary as functions of both the primary air quantity and the damper pressure drop. Therefore, the Standard Rating Conditions of this Standard include a specified damper pressure drop.

Air Moving and Conditioning Association

1. AMCA Standard 300-67. Test Code for Sound Rating

This Code establishes a practical method of determining the sound power level of an Air Moving Device (AMD).

The Code will: (1) Present values that are useful in field applications. (2) Give uniformly reproducible results in all qualified laboratories. (3) Be "practical" in the sense that its accuracy will be satisfactory for all general applications while its operation will not add significantly to the cost of the product.

These aims are achieved by applying standard, readily available, sound measuring instruments to rooms with minimal restrictions on size and construction. The test set-ups are designed to represent general usage of the AMDs tested.

2. AMCA Bulletin 301. Standard Method of Publishing Sound Ratings for Air Moving Devices (1965).

This document establishes a standard method of publishing Sound Ratings for Air Moving Devices.

The purpose of this Standard is to eliminate misunderstandings between the manufacturer and the purchaser and to assist the purchaser in selecting the obtaining the proper product for his particular need.

This Standard applies to: (a) Centrifugal Fans. (b) Axial and Propeller Fans. (c) Power Roof and Wall Ventilators. (d) Steam and Hot Water Unit Heaters.

It is intended that this Standard shall also apply to Central Station Heating, Ventilating and Air Conditioning Units. When a detailed method of publishing sound ratings for these units has been adopted an addendum to this Standard will be issued.

3. AMCA Bulletin 302. Application of Sone Loudness Ratings for Non-Ducted Air Moving Devices (1965).

The AMCA method of rating in sones gives the loudness at a distance of 5 feet from the unit in free space with no nearby reflecting surfaces. Since most practical problems will involve the judgment of loudness within a room, some method is needed to relate the loudness in a given room to the "loudness rating" of the fan.

The charts and formulae given in this bulletin are for the purpose of determining the loudness of fans as installed, and take into consideration the room size and acoustical qualities as well as the number and ratings of the fans. Within the range of 3.5 and 38 sones, these charts are mathematically rigorous, and are sufficiently accurate for engineering applications from 1.5 to 85 sones. For the addition of sounds, it is assumed that the noise spectrums are similar. The room effect chart is for the reverberant field in the room, and applies everywhere except in the space very near to the fan.

4. AMCA Publication 303. Application of Sound Power Ratings for Ducted Air Moving Devices (1965).

AMCA Sound Power Level Ratings are indicators of the sound generated by an Air Moving Device when operated at various points within its normal operating range. The ratings are obtained from tests conducted by the method described in AMCA Standard 300. Test Code for Sound Rating AMDs are published in accordance with AMCA Standard 301, Method of Publishing Sound Ratings for AMDs.

Air Moving Devices that are normally used without ducts are rated in sones. Information on the use of sone ratings is given in AMCA Publication 302, Application of Sone Loudness Ratings.

Air Diffusion Council

1. ADC Standard AD-63. Measurement of Room-to-Room Sound Transmission Through Plenum Air Systems.

The purpose of the measurements covered by this Standard is to determine the sound transmission along a complex path, the incident side or area of which is an opening (which may be fitted with a grille or similar device), the transmitting side or area of which is an identical opening, and the intervening element of which is a ceiling plenum whose characteristics are described. Such paths are commonly used for unducted air handling systems in buildings.

2. ADC Test Code 1062R2. Equipment Test Code (1966).

This Test Code is intended to provide a means for testing and rating air distribution and control devices. It should provide a basis for comparison among the available equipment and also for determining the comfort conditions of occupied rooms in air conditioning, heating and ventilating systems.

The purpose of this Test Code is to present in a single document all those techniques and facilities required for the measurement of performance of air distribution or air terminal devices. Methods of Test Measurement have been established to provide uniform test procedures, equipment and instrumentation with regard to air flow, velocity and pressure, temperature and sound generation.

Home Ventilating Institute

1. HVI Test Procedure. Air Flow Test Procedure (1968).

The general purpose of the HVI Report is:

a. To provide a procedure for the taking of measurements of the sound output of home ventilating equipment.

b. To establish a method for the interpretation and/or presentation of the data obtained from the measurements of (a).

Association of Home Appliance Manufacturers

1. AHAM Standard SR-1. Room Air Conditioner Sound Rating (1971).

The Standard establishes uniform testing conditions. The sound rating of room air conditioners shall be based upon tests made in accordance with ASHRAE Standard 36A-63, Method of Determining Sound Power Levels of Room Air Conditioners and Other Ductless, Through-the-Wall Equipment in test rooms qualified for pure tone response in accordance with Appendix I of this Standard in the one-third octave bands having center frequencies from 100 thru 10,000 Hz, inclusive. Temperature conditions, electrical input, and position of dampers, grilles, and controls shall be maintained continuously for a minimum of one hour before sound measurements are taken to ensure that a stabilized condition has been reached.

National School Supply and Equipment Association, Folding Partition Subsection

1. NSSEA Test Procedure. Testing Procedures for Measuring Sound Transmission Loss through Movable and Folding Walls (1966).

The test procedures detailed in this booklet grew out of a long time need, on the part of school officials, architects and others, for a definitive and workable method of comparing the sound transmission loss characteristics of movable walls.

The procedure for the test itself has been standardized by the American Society for Testing and Materials; (ASTM E90). But it is necessary, in addition, to standardize the way the test specimen is installed, how its construction is certified, and other details of the conduct of the test.

The test results stated in any NSSEA certificate apply to a movable wall tested in accordance with the procedures outlined and under stated laboratory conditions.

Certification of test results will not be construed as certifying that a movable wall of the same construction will give, under other than laboratory conditions, identical results. For in a field installation, the movable wall is not the only path for noise to pass from one room to the next. Other paths may be ceiling plenums, hollow floors, ventilation ducts, windows and doors, or hollow walls.

California Redwood Association

1. CRA Data Sheet 202-6. Redwood Insulation: Heat, Sound and Electricity (1964).

Insulation is the property of a material which impedes the transmission of energy in the form of heat, sound or electricity. California redwood possesses good insulation characteristics in all three cases. Values on its properties are included in the report.

Factory Mutual Systems

1. FMS Loss Prevention Data. 1-11, Insulating and Acoustical Materials (1952).

This data sheet lists those insulating and acoustical materials most commonly used as interior wall and ceiling finish.

Federal Specifications

1. Federal Specification HH-I-545B. Insulation, Thermal and Acoustical (Mineral Fiber, Duct Lining Material) (1971).

This specification covers mineral fiber insulation for lining the interior surfaces of ducts, plenums, and other airhandling equipment, and to provide sound attenuation in systems that handle air up to 250° F.

2. Federal Specification SS-S-111a and Amendment-1. Sound Controlling Materials (Trowel and Spray Applications) (1968).

This specification covers acoustical materials for trowel or spray application.

3. Federal Specification SS-S-118a and Interim Amendment-1. Sound Controlling Blocks and Boards (1967).

This specification covers prefabricated acoustical tiles and panels (blocks and boards) which provide acoustical treatment and interior finish.

American Boat and Yacht Council

1. ABYC Project H-17 (Proposed). Recommended Practices and Standards Covering Insulating, Soundproofing, and Sheathing Materials and Fire Retardent Coatings (1970).

The purpose is to identify recommended practices for the application of interior materials and finishes for the purpose of thermal insulation and soundproofing as they relate to safety and safe operation.

Radio Manufacturers Association

1. RMA Standard SE-105. Microphones for Sound Equipment (1949).

This Standard gives definitions and measurement techniques for a variety of microphones. It discusses microphone response and rating methods.

Compressed Air and Gas Institute

1. CAGI Test Code. CAGI-PNEUROP Test Code for the Measurement of Sound from Pneumatic Equipment (1969).

The Purpose of the code is to provide standard test procedures for the measurement of airborne sound from pneumatic equipment.

This code applies to compressors and peneumatic equipment and specifies procedures and operating conditions acceptable and expedient for use by non-specialists as well as by acoustic engineers.

American Gear Manufacturers Association

1. AGMA Standard 293.03. Specification for Measurement of Sound on High Speed Helical and Herringbone Gear Units (1968).

This Standard applies to gear units which are within the scope of Standard AGMA 421.06, "Standard Practice for High Speed Helical and Herringbone Gear Units", and as produced by the AGMA High Speed Units Manufacturer's Group. It does not include marine propulsion, aerospace, or automotive gearing.

The specifications and procedures apply to sound measurement, testing methods, and limiting values of direct air-borne sound generated by a gear unit, and the auxiliary equipment required for its operation, whose prime mover is not integral with the unit.

Sound level characteristics of a gear unit are affected by types of foundations and room surroundings. Therefore, it should be understood that shop tests may not fully determine the level of sound in the installed locations.

National Electrical Manufacturers Association

1. NEMA Standard SM 33-1964. Gas Turbine Sound and Its Reduction.

This Standards Publication contains information relative to gas turbine inlet and exhaust Sound Pressure Levels and sound reduction to satisfy surrounding neighborhood requirements external to the turbine room in the far field (airborne sound). (Other sources of sound, such as fans for oil coolers, acoustic leakage through buildings housing the equipment, etc., are not covered in this publication.)

National Machine Tool Builders Association

1. NMBTA Standard. Noise Measurement Techniques (1970).

These procedures apply to measurements made in facilities under the control of the machine tool builder. As such it is assumed that the builder will provide a suitable test space so that reasonably accurate noise level data may be obtained and possibly repeated at a later date. Therefore, ambient noise and reverberation correction factors are not included.

To obtain an accurate measure of the noise produced by a machine, the ambient noise level should meet the following conditions:

(a) The ambient level of the frequency band being measured should preferably be at least 10 dB lower than the band level generated by the machine.

(b) The ambient level must remain steady for the duration of the test, or if varying, should not exceed a level 10 dB below that of the machine under test.

Power Saw Manufacturers Association

1. PSMA Standard N1.1-66. Noise Level.

   This Standard establishes a noise level certification procedure for measuring the noise emitted by power saws for infrequent commercial operation in residential areas.

2. PSMA Standard N2.1-67. Noise Octave Band Measurement.

   This Standard establishes a test procedure for measuring noise level at the power saw operator's ear.

Anti-Friction Bearing Manufacturers Association

1. AFBMA Standard No. 13. Rolling Bearing Vibration and Noise (1968).

   The field of application for standards on bearing vibration and noise is not universal. It encompasses the applications where usefulness of these standards as a basis for bearing selection and specification has been proven by sufficient experimental evidence.

   In the current edition of this Standard, only selected methods for the measurement of the (structure-borne) vibration of certain types of ball bearings have been specified. Other vibration measurement methods, as well as methods for the measurement of rolling bearing (air-borne) noise, may be specified in later editions.

Hearing Aid Industry Conference

1. HAIC Standard 61-1. Standard Method of Expressing Hearing-Aid Performance.

   The purpose of this Standard is to provide a uniform method of numerically and graphically expressing certain fundamental performance characteristics of hearing aids in a simple manner, so that those using such data can be assured of its meaning.

2. HAIC Standard 65-1. Interim Bone Conduction Thresholds for Audiometry.

   The purpose of this Standard is to provide an interim industry calibration for bone conduction, and to provide a uniform interim bone threshold for use in audiometry.

Military Specifications

1. MIL-A-8806A, and Amendment-1. Acoustical Noise Level in Aircraft, General Specification for (1966).

   This Specification covers the general requirements for the control of acoustical noise in occupied spaces of aircraft, including the acceptable noise levels and the testing requirements for determining conformance to these levels.

2. MIL-N-83155A, and Amendment-1. Noise Suppressor System, Aircraft Turbine Engine Ground Run-Up, General Specification for (1970).

This Specification covers general design, performance and test of noise suppressor systems used for ground run-up of aircraft turbine engines. The complete requirements for a noise suppressor system applicable to a particular turbine engine shall be stated in the individual equipment specification.

3. MIL-N-83158A. Noise Suppressor Systems, Engine Test Stand A/F32T-2 and A/F32T-3; for Turbojet and Turbofan Engines (1970).

This Specification covers demountable noise suppressor systems for use in performance testing of engines mounted on an A/M37T-6 engine test stand.

4. MIL-S-3151a, and Notice-1. Sound-Level Measuring and Analyzing Equipment (1967).

This Specification covers Sound-Level Measuring and Analyzing Equipment consisting of a Sound-Level Meter, an Octave-Band Analyzer and a Magnetic Tape Recorder. When used in conjunction this equipment forms a single type Sound-Level Measuring and Analyzing System.

5. MIL-S-008806B. Sound Pressure Levels in Aircraft, General Specification for (1970).

This limited coordination military specification has been prepared by the Air Force based upon currently available technical information, but it has not been approved for promulgation as a revision of Military Specification MIL-A-8806. It is subject to modification. However, pending its promulgation as a coordinated military specification, it may be used in procurement.

This Specification covers the general requirements for maximum allowable sound pressure levels in aircraft crew and passenger compartments and the testing requirements for determining conformance to these levels.

APPENDIX A. GLOSSARY

ACCELEROMETER (ACCELERATION PICKUP) -- An electroacoustic transducer that responds to the acceleration of the surface to which the transducer is attached, and delivers essentially equivalent electric waves.

ACOUSTICAL POWER -- See sound power.

ACOUSTICS -- (1) The science of sound, including the generation, transmission, and effects of sound waves, both audible and inaudible. (2) The acoustics of an auditorium or of a room, the totality of those physical qualities (such as size, shape, amount of sound absorption, and amount of noise) which determine the audibility and perception of speech and music.

AIRBORNE SOUND -- Sound that reaches the point of interest by propagation through air.

AMBIENT NOISE -- See background noise.

ANALYSIS -- The analysis of a noise generally refers to the composition of the noise into various frequency bands, such as octaves, third-octaves, etc.

ANECHOIC ROOM -- A room whose boundary walls absorb almost completely sound waves incident upon them, with practically no sound being reflected.

ARTICULATION INDEX (AI) -- A numerically calculated measure of the intelligibility of transmitted or processed speech. It takes into account the limitations of the transmission path and the background noise. The articulation index can range in magnitude between 0 and 1.0. If the AI is less than 0.1, speech intelligibility is generally low. If it is above 0.6, speech intelligibility is generally high.

A-WEIGHTED SOUND LEVEL (dBA) -- A quantity, in decibels, read from a standard sound-level meter that is switched to the weighting network labeled "A". The A-weighting network discriminates against the lower frequencies according to a relationship approximating the auditory sensitivity of the human ear at moderate sound levels. The A-weighted sound level measures approximately the relative "noisiness" of "annoyance" of many common sounds.

AUDIO FREQUENCY -- The frequency of oscillation of an audible sine-wave of sound; any frequency between 20 and 20000 hertz. See also frequency.

AUDIOGRAM -- A graph showing hearing loss as a function of frequency.

AUDIOMETER -- An instrument for measuring hearing sensitivity.

BACKGROUND NOISE -- The total of all noise in a system or situation, independent of the presence of the desired signal.

BAND CENTER FREQUENCY -- The designated mean frequency of a band of noise or other signal. For example, 1000 Hz is the band center frequency for the octave band that extends from 707 Hz to 1414 Hz, or for the third-octave band that extends from 891 Hz to 1123 Hz.

BAND PRESSURE (OR POWER) LEVEL -- The pressure (or power) level for the sound contained within a specified frequency band. The band may be specified either by its lower and upper cut-off frequencies, or by its geometric center frequency. The width of the band is often indicated by a prefatory modifier; e.g., octave band, third-octave band, 10-Hz band.

CONTINUOUS SOUND SPECTRUM -- A continuous sound spectrum is comprised of components which are continuously distributed over a frequency region.

C-WEIGHTED SOUND LEVEL (dBC) -- A quantity, in decibels, read from a standard sound-level meter that is switched to the weighting network labeled "C". The C-weighting network weights the frequencies between 70 Hz and 4000 Hz uniformly, but below and above these limits frequencies are slightly discriminated against. Generally, C-weighted measurements are essentially the same as overall sound-pressure levels, which require no discrimination at any frequency.

CYCLES PER SECOND -- See frequency.

DAMAGE-RISK CRITERIA (HEARING-CONSERVATION CRITERIA) -- Recommended maximum noise levels that for a given pattern of exposure times should, if not exceeded, minimize the risk of damage to the ears of persons exposed to the noise.

DAMPING -- The dissipation of energy with time or distance. The term is generally applied to the attenuation of sound in a structure owing to the internal sound-dissipative properties of the structure or owing to the addition of sound-dissipative materials.

DECIBEL -- The unit in which the levels of various acoustical quantities are expressed. Typical quantities so expressed are sound pressure level, noise level, and sound power level.

DIFFUSE SOUND FIELD -- The presence of many reflected waves (echoes) in a room (or auditorium) having a very small amount of sound absorption, arising from repeated reflections of sound in various directions.

DIRECTIVITY INDEX -- In a given direction from a sound source, the difference in decibels between (a) the sound-pressure level produced by the source in that direction, and (b) the space-average sound-pressure level of that source, measured at the same distance.

DUCT LINING OR WRAPPING -- Usually a sheet of porous material placed on the inner or outer wall(s) of a duct to introduce sound attenuation and heat insulation. It is often used in air conditioning systems. Linings are more effective in attenuating sound that travels inside along the length of a duct, while wrappings are more effective in preventing sound from being radiated from the duct sidewalls into surrounding spaces.

EFFECTIVE PERCEIVED NOISE LEVEL (EPNL) -- A physical measure designed to estimate the effective "noisiness" of a single noise event, usually an aircraft flyover; it is derived from instantaneous PNL values by applying corrections for pure tones and for the duration of the noise.

ELECTROACOUSTICS -- The science and technology of transforming sound waves into currents in electrical circuits (and vice versa), by means of microphones, loudspeakers, and electronic amplifiers and filters.

FARFIELD -- Consider any sound source in free space. At a sufficient distance from the source, the sound pressure level obeys the inverse-square law, and the sound particle velocity is in phase with the sound pressure. This region is called the far field of the sound source. Regions closer to the source, where these two conditions do not hold, constitute the near field. Now consider a sound source within an enclosure. It is also sometimes possible to satisfy the far-field conditions over a limited region between the near field and the reverberant field, if the absorption within the enclosure is not too small so that the near field and the reverberant field merge.

FILTER -- A device that transmits certain frequency components of the signal (sound or electrical) incident upon it, and rejects other frequency components of the incident signal.

FREE SOUND FIELD (FREE FIELD) -- A sound field in which the effects of obstacles or boundaries on sound propagated in that field are negligible.

FREQUENCY -- The number of oscillations per second (a) of a sine-wave of sound, and (b) of a vibrating solid object; now expressed in hertz (abbreviation Hz), formerly in cycles per second (abbreviation cps).

HEARING DISABILITY -- An actual or presumed inability, due to hearing impairment, to remain employed at full wages.

HEARING HANDICAP -- The disadvantage imposed by a hearing impairment sufficient to affect one's efficiency in the situation of everyday living.

HEARING IMPAIRMENT -- A deviation or change for the worse in either hearing structure or function, usually outside the normal range; see hearing loss.

HEARING LOSS -- At a specified frequency, an amount, in decibels, by which the threshold of audibility for that ear exceeds a certain specified audiometric threshold, that is to say, the amount by which a person's hearing is worse than some selected norm. The norm may be the threshold established at some earlier time for that ear, or the average threshold for some large population, or the threshold selected by some standards body for audiometric measurements.

HEARING LOSS FOR SPEECH -- The difference in decibels between the speech levels at which the "average normal" ear and a defective ear, respectively, reach the same intelligibility, often arbitrarily set at 50%.

HERTZ -- See frequency.

IMPACT INSULATION CLASS (IIC) -- A single-figure rating which is intended to permit the comparison of the impact sound insulating merits of floor-ceiling assemblies in terms of a reference contour.

IMPACT SOUND -- The sound arising from the impact of a solid object on an interior surface (wall, floor, or ceiling) of a building. Typical sources are footsteps, dropped objects, etc.

INVERSE-SQUARE LAW -- The inverse-square law describes that acoustic situation where the mean-square sound pressure changes in inverse proportion to the square of the distance from the source. Under this condition the sound-pressure level decreases 6 decibels with each doubling of distance from the source. See also spherical divergence.

ISOLATION -- See vibration isolator.

LEVEL -- The level of an acoustical quantity (e.g., sound pressure), in decibels, is 10 times the logarithm (base 10) of the ratio of the quantity to a reference quantity of the same physical kind.

LINE SPECTRUM -- The spectrum of a sound whose components occur at a number of discrete frequencies.

LOUDNESS -- (1) A listener's perception of the intensity of a strongly-audible sound or noise, (2) The factor n by which a constant-intensity sound or noise exceeds, in the judgment of a listener, the loudness of a 1000 Hz tone heard at a sound pressure 40 dB above threshold. The unit is the sone. See also loudness level.

LOUDNESS LEVEL -- The number, attributed to a constant-intensity sound or noise, of decibels by which a 1000 Hz pure tone, judged by listeners to be as loud as the sound or noise, exceeds the reference level 2×10^{-5} N/m^2. The unit is the phon. See also loudness.

MACH NUMBER -- The ratio of a speed of a moving element to the speed of sound in the surrounding medium.

MASKING -- The action of bringing one sound (audible when heard alone) to inaudibility or to unintelligibility by the introduction of another, usually louder, sound. See masking noise.

MASKING NOISE -- A noise which is intense enough to render inaudible or unintelligible another sound which is simultaneously present.

MICROPHONE -- An electroacoustic transducer that responds to sound waves and delivers essentially equivalent electric waves.

NEAR FIELD -- See far field.

NOISE -- Any sound which is undesirable because it interferes with speech and hearing, or is intense enough to damage hearing, or is otherwise annoying.

NOISE CRITERION (NC) CURVES -- Any of several versions (SC, NC, NCA, PNC) of criteria used for rating the acceptability of continous indoor noise levels, such as produced by air-handling systems.

NOISE EXPOSURE FORECAST (NEF) -- A measure of the total noise exposure near an airport; it is derived from EPNL contours for individual aircraft by including considerations of mix of aircraft, number and time of operations, runway utilization, flight path, and operating procedures.

NOISE INSULATION -- See sound insulation.

NOISE ISOLATION CLASS (NIC) -- A single number rating derived in a prescribed manner from the measured values of noise reduction. It provides an evaluation of the sound isolation between two enclosed spaces that are acoustically connected by one or more paths.

NOISE LEVEL -- See sound level.

NOISE AND NUMBER INDEX (NNI) -- A measure based on perceived noise level and used for rating the noise environment near an airport.

NOISE POLLUTION LEVEL (L_{NP}) -- A measure of the total community noise environment regardless of the types of noise source; it is computed from the "energy mean" of the noise level and the standard deviation of the time variation of noise level.

NOISE REDUCTION COEFFICIENT (NRC) -- The average of the sound absorption coefficients of an acoustical material at 250, 500, 1000, and 2000 Hz, expressed to the nearest integral multiple of 0.05.

NOYS -- A unit used in the calculation of perceived noise level.

OCTAVE -- Any two pure tones, whose ratio of frequencies is exactly two, are said to be "an octave apart", or to be "separated by an octave".

OCTAVE BAND -- All of the components, in a sound spectrum, whose frequencies are between two sine wave components separated by an octave.

OCTAVE-BAND SOUND PRESSURE LEVEL -- The integrated sound pressure level of only those sine-wave components in a specified octave band, for a noise or sound having a wide spectrum.

OSCILLATION -- The variation with time, alternately increasing and decreasing, (a) of some feature of an audible sound, such as the sound pressure, or (b) of some feature of a vibrating solid object, such as the displacement of its surface.

PEAK SOUND PRESSURE -- The maximum instantaneous sound pressure (a) for a transient or impulsive sound of short duration in time, or (b) in a specified time interval for a sound of long duration.

PERCEIVED NOISE LEVEL (PNL) -- The level in dB assigned to a noise by means of a calculation procedure that is based on an approximation to subjective evaluations of "noisiness".

PHASE -- For a particular value of the independent variable, the fractional part of a period through which the independent variable has advanced, measured from an arbitrary reference.

PHON -- The unit of measurement for loudness level.

PITCH -- A listener's perception of the frequency of a pure tone; the higher the frequency, the higher the pitch.

PRESBYCUSIS -- The decline in hearing acuity that normally occurs as a person grows older.

PURE TONE -- A sound wave whose waveform is that of a sine-wave.

RANDOM INCIDENCE -- If an object is in a diffuse sound field, the sound waves that comprise the sound field are said to strike the object from all angles of incidence at random.

RANDOM NOISE -- An oscillation whose instantaneous magnitude is not specified for any given instant of time. It can be described in a statistical sense by probability distribution functions giving the fraction of the total time that the magnitude of the noise lies within a specified range.

RESONANCE -- The relatively large effects produced, e.g., amplitude of vibration, when repetitive sound pressure or force is in approximate synchronism with a free (unforced) vibration of a component or a system.

REVERBERATION -- The persistence of sound in an enclosed space, as a result of multiple reflections, after the sound source has stopped.

REVERBERATION ROOM -- A room having a long reverberation time, especially designed to make the sound field inside it as diffuse (homogeneous) as possible.

REVERBERATION TIME -- The time required for the sound pressure level, arising from reverberation in a room or auditorium and measured from the moment at which the source of sound power is stopped, to die away (decay) by 60 dB.

ROOT-MEAN-SQUARE (RMS) -- The root-mean-square value of a quantity that is varying as a function of time is obtained by squaring the function at each instant, obtaining the average of the squared value over the interval of interest, and taking the square root of this average.

SINE-WAVE -- A sound wave, audible as a pure tone, in which the sound pressure is a sinusoidal function of time; sound pressure $\sim$ sine of (2π x frequency x time).

SONE -- The unit of measurement for loudness.

SONIC BOOM -- The pressure transient produced at an observing point by a vehicle that is moving past (or over) it faster than the speed of sound.

SOUND -- See acoustics (1).

SOUND-ABSORPTION COEFFICIENT (ABSORPTION COEFFICIENT) -- The sound-absorbing ability of a surface is given in terms of a sound-absorption coefficient. This coefficient is defined as the fraction of incident sound energy absorbed or otherwise not reflected by the surface. Unless otherwise specified, a diffuse sound field is assumed. The values of sound-absorption coefficient usually range from about 0.01 for marble slate to about 1.0 for long absorbing wedges such as are used in anechoic chambers.

SOUND INSULATION -- (1) The use of structures and materials designed to reduce the transmission of sound from one room or area to another or from the exterior to the interior of a building. (2) The degree by which sound transmission is reduced by means of sound insulating structures and materials.

SOUND LEVEL (NOISE LEVEL) -- The weighted sound pressure level obtained by use of a sound level meter having a standard frequency-filter for attenuating part of the sound spectrum.

SOUND-LEVEL METER -- An instrument, comprising a microphone, an amplifier, an output meter, and frequency-weighting networks, that is used for the measurement of noise and sound levels in a specified manner.

SOUND POWER -- Of a source of sound, the total amount of acoustical energy radiated into the atmospheric air per unit time.

SOUND POWER LEVEL -- The level of sound power, averaged over a period of time, the reference being 10^{-12} watts.

SOUND PRESSURE -- (1) The minute fluctuations in atmospheric pressure which accompany the passage of a sound wave; the pressure fluctuations on the tympanic membrane are transmitted to the inner ear and give rise to the sensation of audible sound. (2) For a steady sound, the value of the sound pressure averaged over a period of time. (3) Sound pressure is usually measured (a) in dynes per square centimeter (dyn/cm^2), or (b) in newtons per square meter (N/m^2). $1\ N/m^2 = 10\ dyn/cm^2 \approx 10^{-5}$ times the atmospheric pressure.

SOUND PRESSURE LEVEL -- The level of sound pressure; squared and averaged over a period of time, the reference being the square of 2×10^{-5} newtons per square meter.

SOUND TRANSMISSION CLASS, (STC) -- the preferred single figure rating system designed to give an estimate of the sound insulation properties of a partition or a rank ordering of a series of partitions. It is intended for use primarily when speech and office noise constitute the principal noise problem.

SOUND TRANSMISSION COEFFICIENT -- The fraction of incident sound energy transmitted through a structural configuration.

SOUND TRANSMISSION LOSS (TRANSMISSION LOSS)(TL) -- A measure of sound insulation provided by a structural configuration. Expressed in decibels, it is 10 times the logarithm to the base 10 of the reciprocal of the sound transmission coefficient of the configuration.

SPECTRUM -- Of a sound wave, the description of its resolution into components, each of different frequency and (usually) different amplitude and phase.

SPEECH-INTERFERENCE LEVEL (SIL) -- A calculated quantity providing a handy guide to the interfering effect of a noise on speech. The speech-interference level is the arithmetic average of the octave-band sound-pressure levels of the noise in the most important part of the speech frequency range. The levels in the three octave-frequency bands centered at 500, 1000, and 2000 Hz are commonly averaged to determine the speech-interference level.

SPEED (VELOCITY) OF SOUND IN AIR -- The speed of sound in air is 344 m/sec or 1128 ft/sec at 78°F.

SPHERICAL DIVERGENCE -- Spherical divergence is the condition of propagation of spherical waves that relates to the regular decrease in intensity of a spherical sound wave at progressively greater distances from the source. Under this condition the sound-pressure level decreases 6 decibels with each doubling of distance from the source.

SPHERICAL WAVE -- A sound wave in which the surfaces of constant phase are concentric spheres. A small (point) source radiating into an open space produces a free sound field of spherical waves.

STANDING WAVE -- A periodic sound wave having a fixed distribution in space, the result of interference of traveling sound waves of the same frequency and kind. Such sound waves are characterized by the existence of nodes, or partial nodes, and antinodes that are fixed in space.

STEADY-STATE SOUNDS -- Sounds whose average characteristics remain constant in time. Examples of steady-state sounds are a stationary siren, an air-conditioning unit, and an aircraft running up on the ground.

STRUCTUREBORNE SOUND -- Sound that reaches the point of interest, over at least part of its path, by vibrations of a solid structure.

THIRD-OCTAVE BAND -- A frequency band whose cut-off frequencies have a ratio of $2^{1/3}$, which is approximately 1.26. The cut-off frequencies of 891 Hz and 1123 Hz define a third-octave band in common use. See also band center frequency.

THRESHOLD OF AUDIBILITY (THRESHOLD OF DETECTABILITY) -- For a specified signal, the minimum sound-pressure level of the signal that is capable of evoking an auditory sensation in a specified fraction of the trials.

THRESHOLD SHIFT -- An increase in a hearing threshold level that results from exposure to noise.

TRAFFIC NOISE INDEX (TNI) -- A measure of the noise environment created by highways; it is computed from measured values of the sound levels exceeded 10 percent and 90 percent of the time.

TRANSDUCER -- A device capable of being actuated by waves from one or more transmission systems or media and supplying related waves to one or more other transmission systems or media. Examples are microphones, accelerometers, and loudspeakers.

TRANSIENT SOUNDS -- Sounds whose average properties do not remain constant in time. Examples are an aircraft flyover, a passing truck, a sonic boom.

TRANSMISSION LOSS (TL) -- See sound transmission loss.

VIBRATION ISOLATOR -- A resilient support for machinery and other equipment that might be a source of vibration, designed to reduce the amount of vibration transmitted to the building structure.

WAVEFORM -- A presentation of some feature of a sound wave, e.g., the sound pressure, as a graph showing the moment-by-moment variation of sound pressure with time.

WAVEFRONT -- The front surface of a sound wave on its way through the atmosphere.

WAVELENGTH -- For a periodic wave (such as sound in air), the perpendicular distance between analogous points on any two successive waves. The wavelength of sound in air or in water is inversely proportional to the frequency of the sound. Thus the lower the frequency, the longer the wavelength.

Appendix B. The Development of a Measurement System for Sources in Real World Situations

It was previously pointed out that in many cases the noise produced by a given source depends as much on the operational aspects of the device and the surrounding environment as on the sound radiating characteristics of the device itself. In order to further emphasize the considerations which are necessary during the design of a test procedure to accurately characterize such a source, the following detailed example is cited.

Overall truck noise is a combination of engine operating noise, exhaust noise, brake noise, tire noise and aerodynamic noise; however, at speeds of 50 mph and greater, which are quite prevalent on todays interstate highways, the noise from tires predominates provided the truck has a reasonably good exhaust muffler and is in a good state of repair. Because of the almost total lack of an information base of tire noise data available in the public domain, the noise abatement efforts of users and manufacturers of truck tires, state lawmakers and enforcement agencies, and urban planners have been greatly hampered.

For this reason an extensive research program was undertaken (Truck Tire Noise Investigation - an ongoing program being conducted by the National Bureau of Standards under the sponsorship of the Department of Transportation) to identify and quantify the physical parameters which affect the noise generation characteristics of truck tires and develop an information base that may lead to standardized tire noise testing procedures and to highway noise reduction criteria, standards, and regulations.

The data base was to consist of the following three types of information: (1) peak A-weighted sound levels (maximum rms A-weighted sound level during a passby), (2) 1/3-octave spectral data, and (3) directionality information in the form of equal sound level contour plots.

Prior to the design of the measurement systems many questions had to be addressed. This was done through a literature search and a feasibility study. Typical questions to be answered included: What are the influential parameters which affect tire noise? What horizontal locations of the microphones should be utilized? At what height above the road surface should the microphones be placed? Is vertical directionality important? How repeatable are the data at each microphone location for a given set of test conditions; thus, how many repeat runs at each condition are necessary? What effect does grass have on the attenuation of sound generated by truck tires? What are the operational characteristics of the test vehicles? Is there a significant difference in sound level with truck windows open or closed?

These are just some of the considerations that were evaluated prior to the design of the test procedure and measurement system. A careful evaluation of the data resulting from both the literature survey and the feasibility test program led to the establishment of the test procedure utilized throughout the parametric study. Prior to a discussion of the test procedure, a few words of description are necessary to establish the placement of all instrumentation within the test section. Figure B-1 shows the placement of the microphones, photosensors, and the path of the test vehicle.

The microphones, six in all mounted on tripods at a height of 48 inches, were located on a hard surface along a line perpendicular to the path of travel of the test vehicle. The array itself was located midway in the test section. Photosensors, activated by a light beam produced by a spotlight mounted on the side of the truck, were located along the test lane parallel to the path of the vehicle. Although not shown in Figure B-1, the mobile instrumentation van was located 500 feet back from the edge of the runway. Coaxial cables connected the microphones and photocells with the tape recording and monitoring equipment housed in the instrumentation van. The 500 feet distance was dictated because of an airfield ruling (field test site was an airfield runway) and also to avoid unwanted reflection effects.

For any particular run the driver of the test vehicle accelerated the truck to slightly more than the desired speed to compensate for the deceleration characteristics of the particular vehicle. As the truck passed the initial photocell, the tape recorder in the instrumentation van was remotely commanded to turn on.

Since tire noise was being investigated, the testing was performed with the truck in a coasting mode and the engine shut off. The driver shut down the engine prior to entering the test section. The initial photocell, which turned on the recorder, was located so that when the truck passed photocell No. 2 the tape recorder was up to speed (servo-control system in phase lock) and data could be recorded. Data from each microphone were recorded on one of six channels of an F.M. tape recorder. The truck tire noise was recorded during the entire passby over the 1000 foot section. The light beam striking the photocells caused voltage spikes which were recorded on the seventh channel (direct record) of the tape recorder. The photocells (photocells No. 2, 3, 4, 5, 6) were located 250 feet apart along the test section; the "blips" produced by the photocells provided information on truck position versus time which was used for the calculation of vehicle speed and position. As the truck left the test section, a final photocell was triggered which remotely stopped the tape recorder.

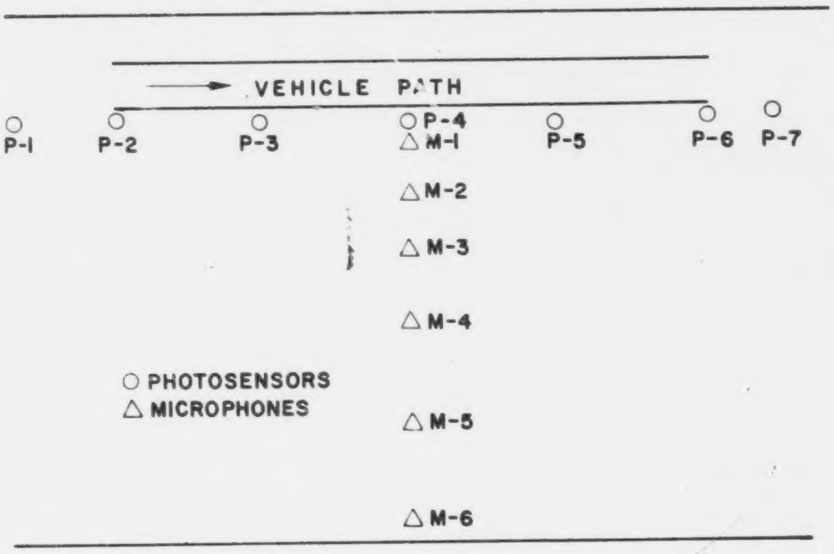


Figure B-1. View of test section showing instrumentation plus vehicle path. (not to scale) Microphones were spaced at various distances as measured from the centerline of the lane in which the truck travelled and along a line perpendicular to the path of the vehicle. Photocells 2, 3, 4, 5, and 6 were spaced 250 feet apart. Photocell No. 1, which remotely turned on the tape recorder was placed 440 feet before photocell No. 2. At a vehicle speed of 60 mph (88 ft/sec), this distance provided the five seconds necessary for the tape recorder to come up to an operating speed of 30 in./s. The final photocell, located immediately adjacent to photocell No. 6, remotely turned off the tape recorder.

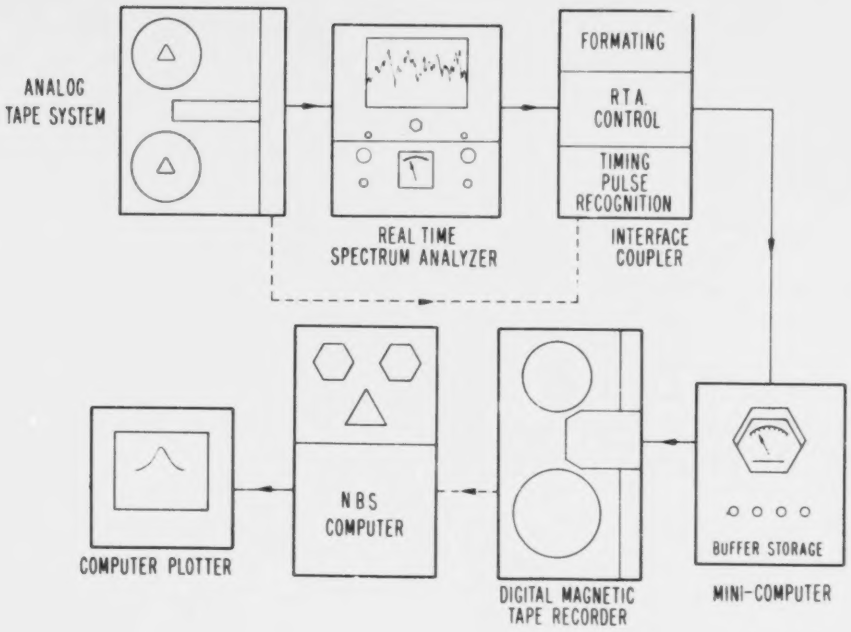

ANALOG TAPE SYSTEM
REAL TIME SPECTRUM ANALYZER
FORMATING
RTA CONTROL
TIMING PULSE RECOGNITION
INTERFACE COUPLER
COMPUTER PLOTTER
NBS COMPUTER
DIGITAL MAGNETIC TAPE RECORDER
BUFFER STORAGE
MINI-COMPUTER

Figure B-2. Data acquisition and recording system.

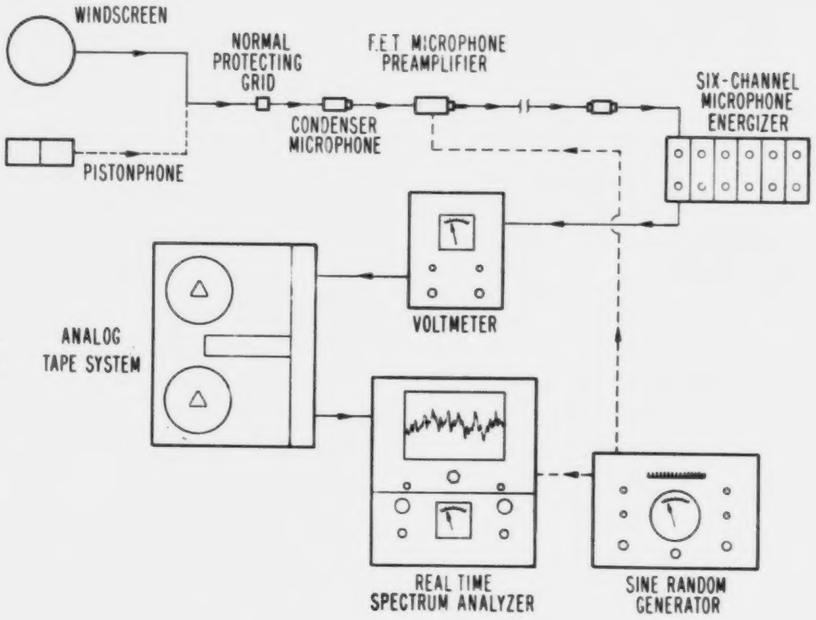

WINDSCREEN
NORMAL PROTECTING GRID
F.E.T MICROPHONE PREAMPLIFIER
SIX-CHANNEL MICROPHONE ENERGIZER
CONDENSER MICROPHONE
PISTONPHONE
VOLTMETER
ANALOG TAPE SYSTEM
REAL TIME SPECTRUM ANALYZER
SINE RANDOM GENERATOR

Figure B-3. Data reduction and analysis system.

B.1. Data Acquisition, Reduction and Analysis System

Figure B-2 identifies the components that constituted the data acquisition system. To describe the workings of the system, the following example is cited with the contribution of each component discussed.

Consider a truck passing an array of microphones. As the truck moved forward, it caused pressure fluctuations which travelled as waves and activated the microphone's diaphragm into vibration. These variations were transduced into an AC voltage which could be recorded for analysis at a later time. The microphone itself was a three-part subsystem comprised of a free-field microphone cartridge, protecting grid, and a microphone preamplifier. It was not practical to locate the tape recorder next to the microphone array since one wanted to minimize undesired reflection effects; therefore, long cables carried the signal from the microphone to the recording facility. To maintain the voltage level of the signal, some line amplification was mandatory. The microphone energizers, in addition to supplying the polarization voltage to the microphones, provided the capability for 20 dB amplification. Once the signal reached the tape recorder, there existed a need for signal conditioning prior to actual recording. The electronic voltmeters provided the capability for amplification/attenuation. The meter scale provided an indication as to whether or not a tape channel had become saturated (i.e., the signal had exceeded the dynamic range of the recorder) and thus the data were not acceptable. The signal was then recorded on one track of the F.M. tape recorder. The measurements were performed out-of-doors; therefore, windscreens were placed over the microphones to minimize the noise produced by wind passing over the microphone. Tests were not conducted when the pavement was wet nor when the wind velocity exceeded 12 mph.

Calibration and system checkout were performed in two steps. A single point calibration utilizing a pistonphone which produced a 124 dB sound pressure level (re 20 $\mu N/m^2$) at a frequency of 250 Hz was used for system calibration in the field. The system checkout also involved running a frequency response on the system. To perform this checkout, the microphone cartridge was removed and replaced with an adapter which allowed the sine-random signal generator to be coupled into the system. The sine-random generator was capable of producing wide band "pink noise", which is white noise passed through a network which weights at -3 dB per octave. When a display unit, such as a real-time analyzer was coupled to the output terminals of the tape recorder, a flat frequency response (constant energy per octave of bandwidth) could be observed. In general, a lack of low frequency response would be indicative of overloading of an amplifier and a lack of high frequency response would be indicative of an amplifier failure. This operation also established the integrity of all connecting cables. During actual testing, the real-time analyzer was used to provide some data with which to judge the progress of the testing prior to the later reduction and analysis of the data on the computer.

Once the data had been recorded, the analog tapes were returned to the laboratory for reduction and analysis. Figure B-3 identifies the equipment which was utilized for analysis purposes. Each tape was played back a channel at a time through the real-time analyzer. An interface-coupler was necessary to make the real-time analyzer compatible with a minicomputer. When a timing signal appeared on the analog tape, the real-time analyzer was commanded to begin analysis. The selection of the appropriate averaging times (and thus the statistical error) is of great importance in obtaining the root mean square (rms) value of the signal (noise). In the case of statistically varying signals such as noise the correct rms value is only obtained if the averaging time is infinite. Since the averaging time in practice cannot be made infinitely long, the "rms value" of the noise fluctuates during the measurements. To obtain a given accuracy in a particular noise measurement it is therefore necessary to increase the averaging time when the absolute bandwidth of the measuring analyzer is decreased. For this program a time constant of .2 second was utilized to obtain the rms value of the level in each one-third octave band over the frequency range of interest at the output of the analyzer. Once all data had been analyzed in one-third octave bands, the computer stored the data and dumped it onto digital magnetic tape. This tape was formatted to be acceptable to the large NBS computer which was utilized for further analysis and graphical plot generation. This instrumentation system provided for efficient data acquisition and data handling for the thousands of data points generated for each truck passby.

In summary, the following were specified as part of the test procedure for this test program:

1. Environmental Conditions: No rain, wind velocity less than 12 mph.
2. Test Site: Flat area free of reflecting surfaces within the area of the measurement positions, a minimum hard surface width of 150 feet and a length such that a vehicle can accelerate to speeds of 60 mph, coast through a test section and then safely stop. Tests on two different pavement surfaces.
3. Microphone Location: Located on a line perpendicular to the path of the vehicle. Mounted on tripods at a height of 48 inches and located at 6, 12, 25, 50, 80, and 130 feet from the centerline of the test lane. All microphones located over a hard surface.
4. Ambient Noise Level: 10 dB or more below the noise to be measured.

5. Instrumentation: Windscreen, pistonphone, condensor microphone, preamplifier, microphone energizer, signal conditioner, F.M. tape recorder (seven channel), a real-time analyzer, signal generator, and computer which meet specified standards.

6. Calibration Procedure: Pistonphone calibration (single point) and specified frequency response or system checkout procedure.

7. Vehicle Mode: Truck coasting with engine off at specified speeds. Truck equipped with standard rubber mud flaps.

8. Test Tires: Various tread designs, degrees of wear, loading conditions. Inflation pressure as specified for given load condition.

9. Photosensors: Located along the path of the vehicle separated by a known distance.

10. Measurements: A-weighted sound level and one-third octave band sound pressure levels. Time constant of analyzer is specified as 0.2 second.

Thus it is easily realized that in order to accurately characterize the noise signature of a source, such as an assemblage of truck tires, which is dependent on the interaction of the source with the surroundings and its operational mode, much more than the sound radiating characteristics of the source itself must be considered. In most cases the instrumentation to perform such test programs exists today; however, the test procedures should be developed on the basis of a thorough consideration of all possible alternative methods. Once a measurement system has been standardized, care must be taken to ensure that the method is not being used under circumstances for which it is not applicable.

Appendix C. Computation of Equivalent Octave Band Sound Pressure Levels from One-third Octave Band Data

Should one have one-third octave band data and wish to convert to octave band data, the following procedure may be utilized,

Step 1. Divide the level in each one-third octave band by 10 and compute the squared pressure ratio. (Since $SPL = 10 \log_{10} (p^2/po^2)$ then $p^2/po^2 = 10^{SPL/10}$)

Step 2. The partial sums of the squared pressure ratios for the three one-third octave bands comprising each octave band are computed and the octave band signal level computed by taking $10 \log_{10}$ (this sum).

This procedure is illustrated on the following page for the aircraft noise spectrum shown in Figure 13, Section 5.

Conversion of 1/3-Octave Readings to Octave Band Levels

1000 Foot Jet Approach

1/3 Octave Bands	Signal Level	Signal ÷10	Squared Pressure Ratio	Partial Sums	Octave Signal Level	Octave Bands
Hz	dB	bel	--	--	dB	Hz
50	81.6	8.16	.145+09			
63	81.0	8.10	.126+09	.142+10	91.5	63
80	90.6	9.06	.115+10			
100	95.2	9.52	.331+10			
125	99.2	9.92	.832+10	.216+11	103.4	125
160	100.0	10.00	.100+11			
200	96.6	9.66	.457+10			
250	104.6	10.46	.288+11	.525+11	107.2	250
315	102.8	10.28	.191+11			
400	106.6	10.66	.457+11			
500	105.2	10.52	.331+11	.979+11	109.9	500
630	102.8	10.28	.191+11			
800	103.0	10.30	.200+11			
1000	99.8	9.98	.955+10	.351+11	105.4	1000
1250	97.4	9.74	.550+10			
1600	95.4	9.54	.347+10			
2000	95.6	9.56	.363+10	.961+10	99.8	2000
2500	94.0	9.40	.251+10			
3150	92.4	9.24	.174+10			
4000	90.0	9.00	.100+10	.337+10	95.3	4000
5000	88.0	8.80	.631+09			
6300	85.6	8.56	.363+09			
8000	81.6	8.16	.145+09	.537+09	87.3	8000
10000	74.6	7.46	.288+08			

Appendix D.

Detailed Calculations for Selected Straight Line Spectra

This appendix contains the details of the calculations of overall sound pressure level (linear dB(L)); A, B and C-weighted sound level; loudness level according to the Stevens and Zwicker methods; and Perceived Noise Level for each of the four selected straight line spectra -- wherein the 1/3-octave band sound pressure levels change with frequency by the following amounts: -6, 0, +3, and +6 dB/octave, as described previously in Section 5.

-6 DB/OCTAVE SLOPE

FREQUENCY	SIGNAL LEVEL, L	DB(L) WEIGHT, W	WEIGHTED LEVEL, X	SQUARED PRESSURE RATIO, Y	RELATIVE CONTRIBUTION OF Y
HZ	DB	DB	BEL	--	--
10.0	--	--	--	--	--
12.5	--	--	--	--	--
16.0	--	--	--	--	--
20.0	--	--	--	--	--
25.0	--	--	--	--	--
31.5	--	--	--	--	--
40.0	--	--	--	--	--
50.0	90.0	--	9.00	.100+10*	.369
63.0	88.0	--	8.80	.631+09	.233
80.0	86.0	--	8.60	.398+09	.147
100.0	84.0	--	8.40	.251+09	.093
125.0	82.0	--	8.20	.158+09	.058
160.0	80.0	--	8.00	.100+09	.037
200.0	78.0	--	7.80	.631+08	.023
250.0	76.0	--	7.60	.398+08	.015
315.0	74.0	--	7.40	.251+08	.009
400.0	72.0	--	7.20	.158+08	.006
500.0	70.0	--	7.00	.100+08	.004
630.0	68.0	--	6.80	.631+07	.002
800.0	66.0	--	6.60	.398+07	.001
1000.0	64.0	--	6.40	.251+07	.001
1250.0	62.0	--	6.20	.158+07	.001
1600.0	60.0	--	6.00	.100+07	.000
2000.0	58.0	--	5.80	.631+06	.000
2500.0	56.0	--	5.60	.398+06	.000
3150.0	54.0	--	5.40	.251+06	.000
4000.0	52.0	--	5.20	.158+06	.000
5000.0	50.0	--	5.00	.100+06	.000
6300.0	48.0	--	4.80	.631+05	.000
8000.0	46.0	--	4.60	.398+05	.000
10000.0	44.0	--	4.40	.251+05	.000
12500.0	42.0	--	4.20	.158+05	.000
16000.0	40.0	--	4.00	.100+05	.000
20000.0	38.0	--	3.80	.631+04	.000
SUM Y				.271+10	
DB(L) = 10 LOG(SUM Y)				94.3	

---

*The notation .100 + 10 means .100 x 10^{10}, .631 + 09 means .631 x 10^{9}, etc.

```
-6 DB/OCTAVE SLOPE



                                                   SQUARED    RELATIVE
FREQUENCY   SIGNAL       DB(A)      WEIGHTED   PRESSURE   CONTRIBUTION
            LEVEL, L   WEIGHT, W    LEVEL, X   RATIO, Y      OF Y

   HZ          DB          DB          BEL        --          --


   10.0        --        -70.4         --         --          --
   12.5        --        -63.4         --         --          --
   16.0        --        -56.7         --         --          --
   20.0        --        -50.5         --         --          --
   25.0        --        -44.7         --         --          --
   31.5        --        -39.4         --         --          --
   40.0        --        -34.6         --         --          --
   50.0       90.0       -30.2        5.98     .955+06      .017
   63.0       88.0       -26.2        6.18     .151+07      .026
   80.0       86.0       -22.5        6.35     .224+07      .039
  100.0       84.0       -19.1        6.49     .309+07      .054
  125.0       82.0       -16.1        6.59     .389+07      .068
  160.0       80.0       -13.4        6.66     .457+07      .079
  200.0       78.0       -10.9        6.71     .513+07      .089
  250.0       76.0        -8.6        6.74     .550+07      .096
  315.0       74.0        -6.6        6.74     .550+07      .096
  400.0       72.0        -4.8        6.72     .525+07      .091
  500.0       70.0        -3.2        6.68     .479+07      .083
  630.0       68.0        -1.9        6.61     .407+07      .071
  800.0       66.0         -.8        6.52     .331+07      .058
 1000.0       64.0          .0        6.40     .251+07      .044
 1250.0       62.0          .6        6.26     .182+07      .032
 1600.0       60.0         1.0        6.10     .126+07      .022
 2000.0       58.0         1.2        5.92     .832+06      .014
 2500.0       56.0         1.3        5.73     .537+06      .009
 3150.0       54.0         1.2        5.52     .331+06      .006
 4000.0       52.0         1.0        5.30     .200+06      .003
 5000.0       50.0          .5        5.05     .112+06      .002
 6300.0       48.0         -.1        4.79     .617+05      .001
 8000.0       46.0        -1.1        4.49     .309+05      .001
10000.0       44.0        -2.5        4.15     .141+05      .000
12500.0       42.0        -4.3        3.77     .589+04      .000
16000.0       40.0        -6.6        3.34     .219+04      .000
20000.0       38.0        -9.3        2.87     .741+03      .000

SUM Y                                          .575+08

DB(A) = 10 LOG(SUM Y)                           77.6
```

```
-6 DB/OCTAVE SLOPE



                                                  SQUARED    RELATIVE
FREQUENCY   SIGNAL       DB(B)      WEIGHTED   PRESSURE   CONTRIBUTION
            LEVEL, L    WEIGHT, W   LEVEL, X   RATIO, Y     OF Y

   HZ          DB          DB          BEL         --         --


   10.0        --        -38.2         --          --         --
   12.5        --        -33.2         --          --         --
   16.0        --        -28.5         --          --         --
   20.0        --        -24.2         --          --         --
   25.0        --        -20.4         --          --         --
   31.5        --        -17.1         --          --         --
   40.0        --        -14.2         --          --         --
   50.0       90.0       -11.6        7.84     .692+08      .132
   63.0       88.0        -9.3        7.87     .741+08      .141
   80.0       86.0        -7.4        7.86     .724+08      .138
  100.0       84.0        -5.6        7.84     .692+08      .132
  125.0       82.0        -4.2        7.78     .603+08      .115
  160.0       80.0        -3.0        7.70     .501+08      .095
  200.0       78.0        -2.0        7.60     .398+08      .076
  250.0       76.0        -1.3        7.47     .295+08      .056
  315.0       74.0         -.8        7.32     .209+08      .040
  400.0       72.0         -.5        7.15     .141+08      .027
  500.0       70.0         -.3        6.97     .933+07      .018
  630.0       68.0         -.1        6.79     .617+07      .012
  800.0       66.0          .0        6.60     .398+07      .008
 1000.0       64.0          .0        6.40     .251+07      .005
 1250.0       62.0          .0        6.20     .158+07      .003
 1600.0       60.0          .0        6.00     .100+07      .002
 2000.0       58.0         -.1        5.79     .617+06      .001
 2500.0       56.0         -.2        5.58     .380+06      .001
 3150.0       54.0         -.4        5.36     .229+06      .000
 4000.0       52.0         -.7        5.13     .135+06      .000
 5000.0       50.0        -1.2        4.88     .759+05      .000
 6300.0       48.0        -1.9        4.61     .407+05      .000
 8000.0       46.0        -2.9        4.31     .204+05      .000
10000.0       44.0        -4.3        3.97     .933+04      .000
12500.0       42.0        -6.1        3.59     .389+04      .000
16000.0       40.0        -8.4        3.16     .145+04      .000
20000.0       38.0       -11.1        2.69     .490+03      .000

SUM Y                                          .526+09

DB(B) = 10 LOG(SUM Y)                           87.2
```

```
-6 DB/OCTAVE SLOPE


                                                     SQUARED    RELATIVE
FREQUENCY   SIGNAL       DB(C)      WEIGHTED   PRESSURE   CONTRIBUTION
            LEVEL, L    WEIGHT, W   LEVEL, X   RATIO, Y     OF Y

   HZ          DB          DB          BEL         --          --


   10.0        --        -14.3         --          --          --
   12.5        --        -11.2         --          --          --
   16.0        --         -8.5         --          --          --
   20.0        --         -6.2         --          --          --
   25.0        --         -4.4         --          --          --
   31.5        --         -3.0         --          --          --
   40.0        --         -2.0         --          --          --
   50.0       90.0        -1.3        8.87     .741+09        324
   63.0       88.0         -.8        8.72     .525+09       .231
   80.0       86.0         -.5        8.55     .355+09       .156
  100.0       84.0         -.3        8.37     .234+09       .103
  125.0       82.0         -.2        8.18     .151+09       .067
  160.0       80.0         -.1        7.99     .977+08       .043
  200.0       78.0          .0        7.80     .631+08       .028
  250.0       76.0          .0        7.60     .398+08       .017
  315.0       74.0          .0        7.40     .251+08       .011
  400.0       72.0          .0        7.20     .158+08       .007
  500.0       70.0          .0        7.00     .100+08       .004
  630.0       68.0          .0        6.80     .631+07       .003
  800.0       66.0          .0        6.60     .398+07       .002
 1000.0       64.0          .0        6.40     .251+07       .001
 1250.0       62.0          .0        6.20     .158+07       .001
 1600.0       60.0         -.1        5.99     .977+06       .000
 2000.0       58.0         -.2        5.78     .603+06       .000
 2500.0       56.0         -.3        5.57     .372+06       .000
 3150.0       54.0         -.5        5.35     .224+06       .000
 4000.0       52.0         -.8        5.12     .132+06       .000
 5000.0       50.0        -1.3        4.87     .741+05       .000
 6300.0       48.0        -2.0        4.60     .398+05       .000
 8000.0       46.0        -3.0        4.30     .200+05       .000
10000.0       44.0        -4.4        3.96     .912+04       .000
12500.0       42.0        -6.2        3.58     .360+04       .000
16000.0       40.0        -8.5        3.15     .141+04       .000
20000.0       38.0       -11.2        2.68     .479+03       .000

SUM Y                                          .228+10

DB(C) = 10 LOG(SUM Y)                           93.6
```

```
STEVENS SONES, PHONS, FROM OCTAVE BAND LEVELS

-6 DB/OCTAVE SLOPE

                         FREQUENCY   SIGNAL   LOUDNESS
                                     LEVEL    INDEX

                            HZ         DB       --

                           63.0       93.1     17.5
                          125.0       87.1     14.4
                          250.0       81.1     11.8
                          500.0       75.1      9.9
                         1000.0       69.1      8.3
                         2000.0       63.1      7.0
                         4000.0       57.1      5.8
                         8000.0       51.1      4.9
                        16000.0       45.1      1.9

SUM OF LOUDNESS INDICES                        81.5
SUBTRACT MAXIMUM LOUDNESS INDEX              - 17.5

                                               64.0
MULTIPLY BY .3                               X   .3

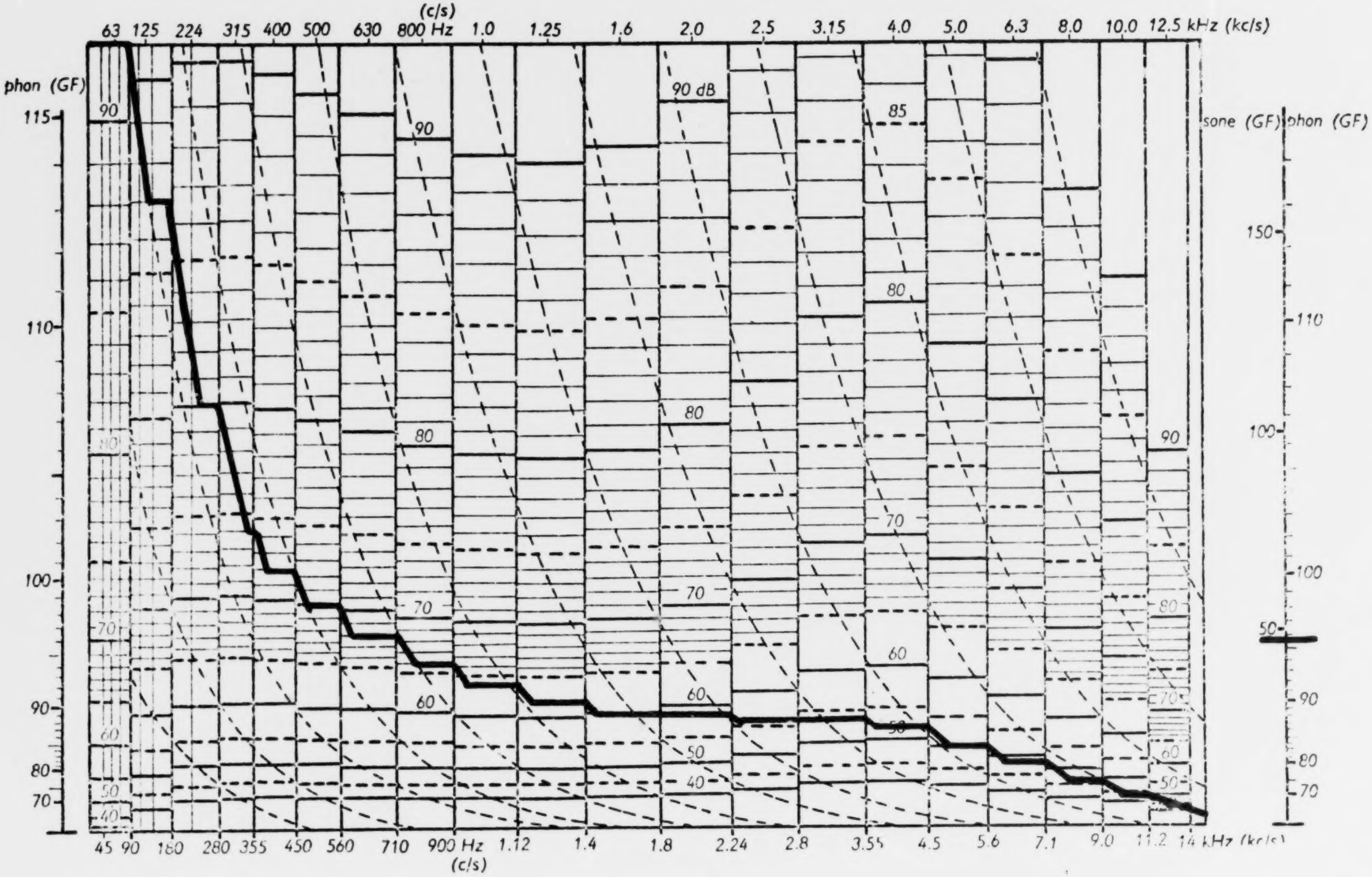
                                               19.2
ADD MAXIMUM LOUDNESS INDEX                   + 17.5

SONES                                          36.7

LOG2 SONES = (LOG10 SONES)/.301                 5.20
                                             X 10.
MULTIPLY BY 10.
                                               52.0
ADD 40.                                      + 40.

PHONS                                          92.0
```

Zwicker sones, phons, from 1/3 octave bands
-6 dB/Octave Slope -- 95.5 Phons



```
KRYTER PERCEIVED NOISE LEVEL FROM 1/3 OCTAVE BANDS

-6 DB/OCTAVE SLOPE

           FREQUENCY  SIGNAL  PERCEIVED
                      LEVEL   NOISINESS

              HZ        DB      NOYS

             50.0      90.0     13.5
             63.0      88.0     13.0
             80.0      86.0     12.7
            100.0      84.0     13.0
            125.0      82.0     12.1
            160.0      80.0     11.3
            200.0      78.0     11.3
            250.0      76.0     10.6
            315.0      74.0      9.6
            400.0      72.0      9.2
            500.0      70.0      8.0
            630.0      68.0      7.0
            800.0      66.0      6.1
           1000.0      64.0      5.3
           1250.0      62.0      5.3
           1600.0      60.0      6.0
           2000.0      58.0      6.0
           2500.0      56.0      6.0
           3150.0      54.0      5.6
           4000.0      52.0      4.9
           5000.0      50.0      4.0
           6300.0      48.0      3.2
           8000.0      46.0      2.3
          10000.0      44.0      1.3

SUM OF NOY VALUES               187.3
SUBTRACT MAXIMUM NOY VALUE     - 13.5

                                173.8
MULTIPLY BY .15                X   .15

                                 26.1
ADD MAXIMUM NOY VALUE          + 13.5

N                                39.6

LOG N                            1.60
MULTIPLY BY 33.3               X33.3

                                 53.2
ADD 40.                        + 40.

PERCEIVED NOISE LEVEL, PNL       93.2

ADD TONE CORRECTION            +   .0
TONE CORRECTED PERCEIVED
NOISE LEVEL,PNLT                 93.2
```

```
0 DB/OCTAVE SLOPE



                                                    SQUARED    RELATIVE
FREQUENCY   SIGNAL       DB(L)      WEIGHTED    PRESSURE   CONTRIBUTION
            LEVEL, L   WEIGHT, W    LEVEL, X    RATIO, Y      OF Y

   HZ.         DB          DB          BEL          --          --


   10.0        --          --          --           --          --
   12.5        --          --          --           --          --
   16.0        --                      --           --          --
   20.0        --          --          --           --          --
   25.0        --          --          --           --          --
   31.5        --          --          --           --          --
   40.0        --          --          --           --          --
   50.0       80.0         --         8.00       .100+09      .037
   63.0       80.0         --         8.00       .100+09      .037
   80.0       80.0         --         8.00       .100+09      .037
  100.0       80.0         --         8.00       .100+09      .037
  125.0       80.0         --         8.00       .100+09      .037
  160.0       80.0         --         8.00       .100+09      .037
  200.0       80.0         --         8.00       .100+09      .037
  250.0       80.0         --         8.00       .100+09      .037
  315.0       80.0         --         8.00       .100+09      .037
  400.0       80.0         --         8.00       .100+09      .037
  500.0       80.0         --         8.00       .100+09      .037
  630.0       80.0         --         8.00       .100+09      .037
  800.0       80.0         --         8.00       .100+09      .037
 1000.0       80.0         --         8.00       .100+09      .037
 1250.0       80.0         --         8.00       .100+09      .037
 1600.0       80.0         --         8.00       .100+09      .037
 2000.0       80.0         --         8.00       .100+09      .037
 2500.0       80.0         --         8.00       .100+09      .037
 3150.0       80.0         --         8.00       .100+09      .037
 4000.0       80.0         --         8.00       .100+09      .037
 5000.0       80.0         --         8.00       .100+09      .037
 6300.0       80.0         --         8.00       .100+09      .037
 8000.0       80.0         --         8.00       .100+09      .037
10000.0       80.0         --         8.00       .100+09      .037
12500.0       80.0         --         8.00       .100+09      .037
16000.0       80.0         --         8.00       .100+09      .037
20000.0       80.0         --         8.00       .100+09      .037

SUM Y                                            .271+10

DB(L) = 10 LOG(SUM Y)                             94.3
```

```
0 DB/OCTAVE SLOPE


                                                            SQUARED     RELATIVE
FREQUENCY    SIGNAL        DB(A)       WEIGHTED    PRESSURE    CONTRIBUTION
             LEVEL, L     WEIGHT, W    LEVEL, X    RATIO, Y      OF Y

   HZ           DB           DB           BEL          --           --


   10.0         --         -70.4          --           --           --
   12.5         --         -63.4          --           --           --
   16.0         --         -56.7          --           --           --
   20.0         --         -50.5          --           --           --
   25.0         --         -44.7          --           --           --
   31.5         --         -39.4          --           --           --
   40.0         --         -34.6          --           --           --
   50.0        80.0        -30.2         4.98       .959+05        .000
   63.0        80.0        -26.2         5.38       .241+06        .000
   80.0        80.0        -22.5         5.75       .565+06        .000
  100.0        80.0        -19.1         6.09       .124+07        .001
  125.0        80.0        -16.1         6.39       .247+07        .002
  160.0        80.0        -13.4         6.66       .459+07        .003
  200.0        80.0        -10.9         6.91       .817+07        .005
  250.0        80.0         -8.6         7.14       .139+08        .009
  315.0        80.0         -6.6         7.34       .220+08        .014
  400.0        80.0         -4.8         7.52       .333+08        .021
  500.0        80.0         -3.2         7.68       .481+08        .031
  630.0        80.0         -1.9         7.81       .649+08        .041
  800.0        80.0          -.8         7.92       .836+08        .053
 1000.0        80.0           .0         8.00       .100+09        .064
 1250.0        80.0           .6         8.06       .115+09        .074
 1600.0        80.0          1.0         8.10       .126+09        .081
 2000.0        80.0          1.2         8.12       .132+09        .084
 2500.0        80.0          1.3         8.13       .136+09        .086
 3150.0        80.0          1.2         8.12       .132+09        .084
 4000.0        80.0          1.0         8.10       .126+09        .081
 5000.0        80.0           .5         8.05       .113+09        .072
 6300.0        80.0          -.1         7.99       .982+08        .063
 8000.0        80.0         -1.1         7.89       .780+08        .050
10000.0        80.0         -2.5         7.75       .565+08        .036
12500.0        80.0         -4.3         7.57       .373+08        .024
16000.0        80.0         -6.6         7.34       .220+08        .014
20000.0        80.0         -9.3         7.07       .118+08        .008

SUM Y                                               .157+10

DB(A) = 10 LOG(SUM Y)                                92.0
```

```
0 DB/OCTAVE SLOPE



                                                     SQUARED    RELATIVE
FREQUENCY   SIGNAL        DB(B)      WEIGHTED   PRESSURE   CONTRIBUTION
            LEVEL, L   WEIGHT, W    LEVEL, X   RATIO, Y      OF Y

   HZ          DB          DB          BEL         --           --


   10.0        --        -38.2          --          --           --
   12.5        --        -33.2          --          --           --
   16.0        --        -28.5          --          --           --
   20.0        --        -24.2          --          --           --
   25.0        --        -20.4          --          --           --
   31.5        --        -17.1          --          --           --
   40.0        --        -14.2          --          --           --
   50.0       80.0       -11.6        6.84     .695+07        .004
   63.0       80.0        -9.3        7.07     .118+08        .007
   80.0       80.0        -7.4        7.26     .183+08        .011
  100.0       80.0        -5.6        7.44     .277+08        .016
  125.0       80.0        -4.2        7.58     .382+08        .022
  160.0       80.0        -3.0        7.70     .504+08        .030
  200.0       80.0        -2.0        7.80     .634+08        .037
  250.0       80.0        -1.3        7.87     .745+08        .044
  315.0       80.0         -.8        7.92     .836+08        .049
  400.0       80.0         -.5        7.95     .895+08        .052
  500.0       80.0         -.3        7.97     .938+08        .055
  630.0       80.0         -.1        7.99     .982+08        .058
  800.0       80.0          .0        8.00     .100+09        .059
 1000.0       80.0          .0        8.00     .100+09        .059
 1250.0       80.0          .0        8.00     .100+09        .059
 1600.0       80.0          .0        8.00     .100+09        .059
 2000.0       80.0         -.1        7.99     .982+08        .058
 2500.0       80.0         -.2        7.98     .959+08        .056
 3150.0       80.0         -.4        7.96     .916+08        .054
 4000.0       80.0         -.7        7.93     .855+08        .050
 5000.0       80.0        -1.2        7.88     .762+08        .045
 6300.0       80.0        -1.9        7.81     .649+08        .038
 8000.0       80.0        -2.9        7.71     .515+08        .030
10000.0       80.0        -4.3        7.57     .373+08        .022
12500.0       80.0        -6.1        7.39     .247+08        .014
16000.0       80.0        -8.4        7.16     .145+08        .009
20000.0       80.0       -11.1        6.89     .780+07        .005

SUM Y                                          .171+10

DB(B) = 10 LOG(SUM Y)                           92.3
```

```
0 DB/OCTAVE SLOPE



                                                          SQUARED     RELATIVE
FREQUENCY    SIGNAL        DB(C)      WEIGHTED    PRESSURE    CONTRIBUTION
             LEVEL, L    WEIGHT, W    LEVEL, X    RATIO, Y      OF Y

   HZ           DB           DB          BEL          --           --


    10.0        --        -14.3          --           --           --
    12.5        --        -11.2          --           --           --
    16.0        --         -8.5          --           --           --
    20.0        --         -6.2          --           --           --
    25.0        --         -4.4          --           --           --
    31.5        --         -3.0          --           --           --
    40.0        --         -2.0          --           --           --
    50.0       80.0        -1.3         7.87      .745+08        .034
    63.0       80.0         -.8         7.92      .836+08        .038
    80.0       80.0         -.5         7.95      .895+08        .041
   100.0       80.0         -.3         7.97      .938+08        .043
   125.0       80.0         -.2         7.98      .959+08        .044
   160.0       80.0         -.1         7.99      .982+08        .045
   200.0       80.0          .0         8.00      .100+09        .046
   250.0       80.0          .0         8.00      .100+09        .046
   315.0       80.0          .0         8.00      .100+09        .046
   400.0       80.0          .0         8.00      .100+09        .046
   500.0       80.0          .0         8.00      .100+09        .046
   630.0       80.0          .0         8.00      .100+09        .046
   800.0       80.0          .0         8.00      .100+09        .046
  1000.0       80.0          .0         8.00      .100+09        .046
  1250.0       80.0          .0         8.00      .100+09        .046
  1600.0       80.0         -.1         7.99      .982+08        .045
  2000.0       80.0         -.2         7.98      .959+08        .044
  2500.0       80.0         -.3         7.97      .938+08        .043
  3150.0       80.0         -.5         7.95      .895+08        .041
  4000.0       80.0         -.8         7.92      .836+08        .038
  5000.0       80.0        - .3         7.87      .745+08        .034
  6300.0       80.0        -2.0         7.80      .634+08        .029
  8000.0       80.0        -3.0         7.70      .504+08        .023
 10000.0       80.0        -4.4         7.56      .365+08        .017
 12500.0       80.0        -6.2         7.38      .241+08        .011
 16000.0       80.0        -8.5         7.15      .142+08        .007
 20000.0       80.0       -11.2         6.88      .762+07        .004

SUM Y                                             .217+10

DB(C) = 10 LOG(SUM Y)                              93.4
```

```
STEVENS SONES, PHONS, FROM OCTAVE BAND LEVELS

0 DB/OCTAVE SLOPE

                        FREQUENCY  SIGNAL  LOUDNESS
                                   LEVEL   INDEX


                           HZ        DB       --

                          63.0      84.8      9.3
                         125.0      84.8     12.6
                         250.0      84.8     15.3
                         500.0      84.8     18.7
                        1000.0      84.8     23.0
                        2000.0      84.8     28.5
                        4000.0      84.8     35.3
                        8000.0      84.8     44.0
                       16000.0      84.8     21.4

SUM OF LOUDNESS INDICES                     208.1
SUBTRACT MAXIMUM LOUDNESS INDEX            - 44.0

                                            164.1
MULTIPLY BY .3                             X   .3

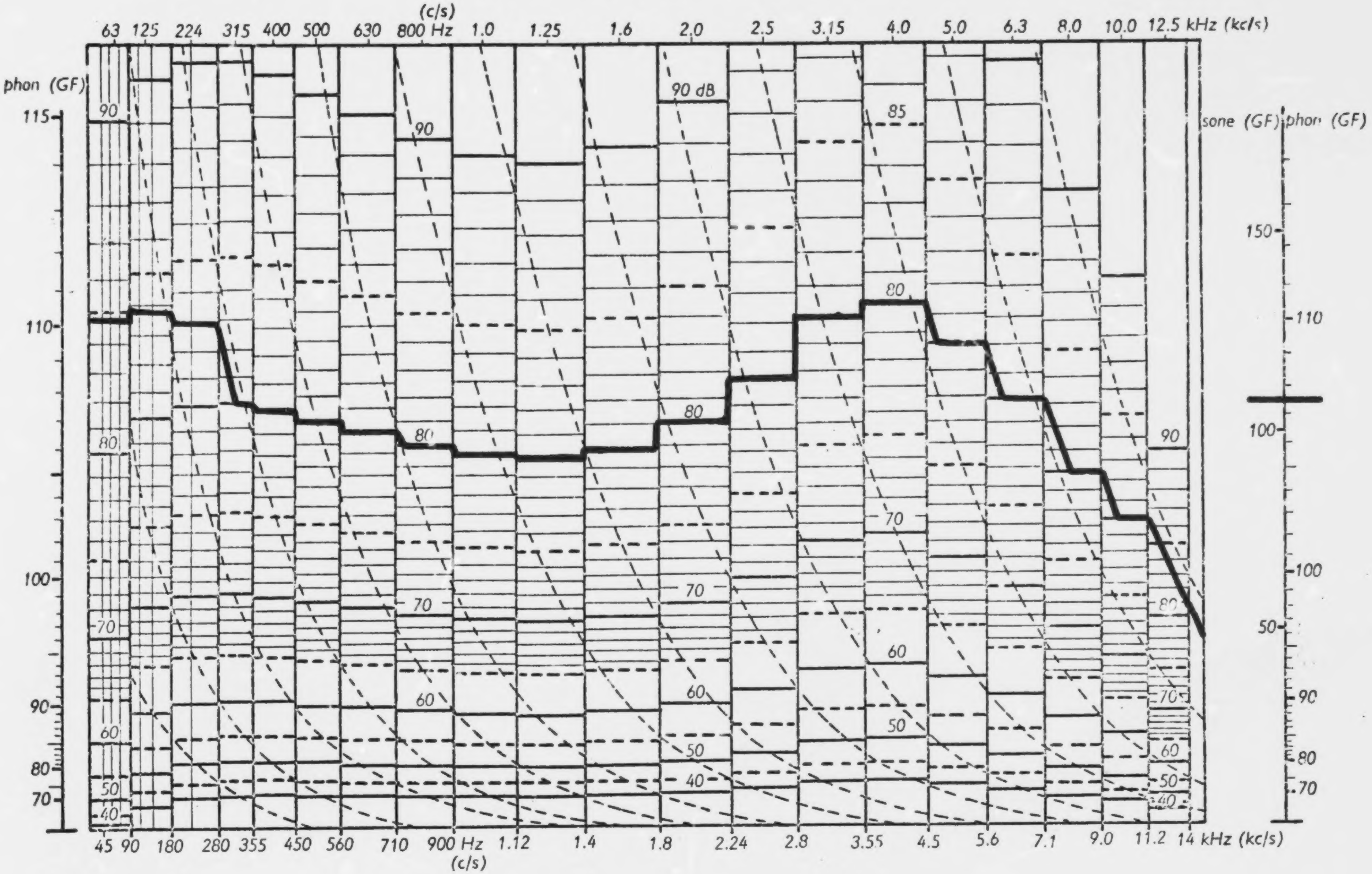
                                             49.2
ADD MAXIMUM LOUDNESS INDEX                 + 44.0

SONES                                        93.2

LOG2 SONES = (LOG10 SONES)/.301              6.54
                                           X 10.
MULTIPLY BY 10.
                                             65.4
ADD 40.                                    + 40.

PHONS                                       105.4
```

Zwicker sones, phons, from 1/3 octave bands
0 dB/Octave Slope -- 107.5 Phons



```
KRYTER PERCEIVED NOISE LEVEL FROM 1/3 OCTAVE BANDS

0 DB/OCTAVE SLOPE

              FREQUENCY  SIGNAL  PERCEIVED
                          LEVEL  NOISINESS

                   HZ       DB       NOYS

                 50.0     80.0       5.0
                 63.0     80.0       6.5
                 80.0     80.0       7.7
                100.0     80.0       9.9
                125.0     80.0      10.6
                160.0     80.0      11.3
                200.0     80.0      13.0
                250.0     80.0      13.9
                315.0     80.0      14.9
                400.0     80.0      16.0
                500.0     80.0      16.0
                630.0     80.0      16.0
                800.0     80.0      16.0
               1000.0     80.0      16.0
               1250.0     80.0      18.4
               1600.0     80.0      23.9
               2000.0     80.0      27.5
               2500.0     80.0      31.5
               3150.0     80.0      33.8
               4000.0     80.0      33.8
               5000.0     80.0      31.5
               6300.0     80.0      29.4
               8000.0     80.0      23.9
              10000.0     80.0      19.4

SUM OF NOY VALUES                  446.1
SUBTRACT MAXIMUM NOY VALUE        - 33.8

                                   412.3
MULTIPLY BY .15                   X   .15

                                    61.8
ADD MAXIMUM NOY VALUE             + 33.8

N                                   95.6

LOG N                               1.98
MULTIPLY BY 33.3                  X33.3

                                    66.0
ADD 40.                           + 40.

PERCEIVED NOISE LEVEL, PNL         106.0

ADD TONE CORRECTION               +    .0
TONE CORRECTED PERCEIVED
NOISE LEVEL,PNLT                   106.0
```

NOT REPRODUCIBLE

```
+3 DB/OCTAVE SLOPE (WHITE NOISE)


                                                        SQUARED    RELATIVE
FREQUENCY   SIGNAL       DB(L)      WEIGHTED   PRESSURE   CONTRIBUTION
            LEVEL, L   WEIGHT, W   LEVEL, X   RATIO, Y     OF Y

    HZ         DB          DB          BEL         --          --


   10.0        --          --          --          --          --
   12.5        --          --          --          --          --
   16.0        --          --          --          --          --
   20.0        --          --          --          --          --
   25.0        --          --          --          --          --
   31.5        --          --          --          --          --
   40.0        --          --          --          --          --
   50.0       61.5         --         6.15      .140+07      .001
   63.0       62.5         --         6.25      .177+07      .001
   80.0       63.5         --         6.35      .222+07      .001
  100.0       64.5         --         6.45      .280+07      .001
  125.0       65.5         --         6.55      .352+07      .001
  160.0       66.5         --         6.65      .444+07      .002
  200.0       67.5         --         6.75      .558+07      .002
  250.0       68.5         --         6.85      .703+07      .003
  315.0       69.5         --         6.95      .885+07      .003
  400.0       70.5         --         7.05      .111+08      .004
  500.0       71.5         --         7.15      .140+08      .005
  630.0       72.5         --         7.25      .177+08      .007
  800.0       73.5         --         7.35      .222+08      .008
 1000.0       74.5         --         7.45      .280+08      .010
 1250.0       75.5         --         7.55      .352+08      .013
 1600.0       76.5         --         7.65      .444+08      .016
 2000.0       77.5         --         7.75      .558+08      .021
 2500.0       78.5         --         7.85      .703+08      .026
 3150.0       79.5         --         7.95      .885+08      .033
 4000.0       80.5         --         8.05      .111+09      .041
 5000.0       81.5         --         8.15      .140+09      .052
 6300.0       82.5         --         8.25      .177+09      .065
 8000.0       83.5         --         8.35      .222+09      .082
10000.0       84.5         --         8.45      .280+09      .103
12500.0       85.5         --         8.55      .352+09      .130
16000.0       86.5         --         8.65      .444+09      .164
20000.0       87.5         --         8.75      .558+09      .206

SUM Y                                           .271+10

DB(L) = 10 LOG(SUM Y)                            94.3
```

```
+3 DB/OCTAVE SLOPE (WHITE NOISE)


                                                        SQUARED      RELATIVE
FREQUENCY   SIGNAL       DB(A)       WEIGHTED     PRESSURE     CONTRIBUTION
            LEVEL, L   WEIGHT, W    LEVEL, X     RATIO, Y       OF Y

   HZ          DB          DB           BEL           --            --


   10.0        --        -70.4          --            --            --
   12.5        --        -63.4          --            --            --
   16.0        --        -56.7          --            --            --
   20.0        --        -50.5          --            --            --
   25.0        --        -44.7          --            --            --
   31.5        --        -39.4          --            --            --
   40.0        --        -34.6          --            --            --
   50.0       61.5       -30.2         3.13        .134+04         .000
   63.0       62.5       -26.2         3.63        .424+04         .000
   80.0       63.5       -22.5         4.10        .125+05         .000
  100.0       64.5       -19.1         4.54        .344+05         .000
  125.0       65.5       -16.1         4.94        .865+05         .000
  160.0       66.5       -13.4         5.31        .203+06         .000
  200.0       67.5       -10.9         5.66        .454+06         .000
  250.0       68.5        -8.6         5.99        .971+06         .001
  315.0       69.5        -6.6         6.29        .194+07         .001
  400.0       70.5        -4.8         6.57        .369+07         .002
  500.0       71.5        -3.2         6.83        .671+07         .004
  630.0       72.5        -1.9         7.06        .114+08         .007
  800.0       73.5         -.8         7.27        .185+08         .012
 1000.0       74.5          .0         7.45        .280+08         .018
 1250.0       75.5          .6         7.61        .405+08         .026
 1600.0       76.5         1.0         7.75        .558+08         .036
 2000.0       77.5         1.2         7.87        .736+08         .048
 2500.0       78.5         1.3         7.98        .948+08         .061
 3150.0       79.5         1.2         8.07        .117+09         .075
 4000.0       80.5         1.0         8.15        .140+09         .091
 5000.0       81.5          .5         8.20        .157+09         .102
 6300.0       82.5         -.1         8.24        .173+09         .112
 8000.0       83.5        -1.1         8.24        .173+09         .112
10000.0       84.5        -2.5         8.20        .157+09         .102
12500.0       85.5        -4.3         8.12        .131+09         .085
16000.0       86.5        -6.6         7.99        .971+08         .063
20000.0       87.5        -9.3         7.82        .656+08         .042

SUM Y                                              .155+10

DB(A) = 10 LOG(SUM Y)                               91.9
```

```
+3 DB/OCTAVE SLOPE (WHITE NOISE)


                                                        SQUARED    RELATIVE
FREQUENCY   SIGNAL      DB(B)     WEIGHTED   PRESSURE   CONTRIBUTION
            LEVEL, L   WEIGHT, W   LEVEL, X   RATIO, Y    OF Y

   HZ          DB          DB         BEL         --          --


   10.0        --        -38.2        --          --          --
   12.5        --        -33.2        --          --          --
   16.0        --        -28.5        --          --          --
   20.0        --        -24.2        --          --          --
   25.0        --        -20.4        --          --          --
   31.5        --        -17.1        --          --          --
   40.0        --        -14.2        --          --          --
   50.0       61.5       -11.6       4.99     .971+05       .000
   63.0       62.5        -9.3       5.32     .207+06       .000
   80.0       63.5        -7.4       5.61     .405+06       .000
  100.0       64.5        -5.6       5.89     .771+06       .001
  125.0       65.5        -4.2       6.13     .134+07       .001
  160.0       66.5        -3.0       6.35     .222+07       .002
  200.0       67.5        -2.0       6.55     .352+07       .003
  250.0       68.5        -1.3       6.72     .521+07       .005
  315.0       69.5         -.8       6.87     .736+07       .007
  400.0       70.5         -.5       7.00     .993+07       .009
  500.0       71.5         -.3       7.12     .131+08       .012
  630.0       72.5         -.1       7.24     .173+08       .015
  800.0       73.5          .0       7.35     .222+08       .020
 1000.0       74.5          .0       7.45     .280+08       .025
 1250.0       75.5          .0       7.55     .352+08       .031
 1600.0       76.5          .0       7.65     .444+08       .040
 2000.0       77.5         -.1       7.74     .546+08       .049
 2500.0       78.5         -.2       7.83     .671+08       .060
 3150.0       79.5         -.4       7.91     .807+08       .072
 4000.0       80.5         -.7       7.98     .948+08       .085
 5000.0       81.5        -1.2       8.03     .106+09       .095
 6300.0       82.5        -1.9       8.06     .114+09       .102
 8000.0       83.5        -2.9       8.06     .114+09       .102
10000.0       84.5        -4.3       8.02     .104+09       .093
12500.0       85.5        -6.1       7.94     .865+08       .077
16000.0       86.5        -8.4       7.81     .641+08       .057
20000.0       87.5       -11.1       7.64     .434+08       .039

SUM Y                                         .112+10

DB(B) = 10 LOG(SUM Y)                          90.5
```

```
+3 DB/OCTAVE SLOPE (WHITE NOISE)


                                                      SQUARED     RELATIVE
FREQUENCY   SIGNAL       DB(C)      WEIGHTED   PRESSURE    CONTRIBUTION
            LEVEL, L   WEIGHT, W   LEVEL, X    RATIO, Y      OF Y

   HZ          DB         DB          BEL          --          --


   10.0        --       -14.3          --          --          --
   12.5        --       -11.2          --          --          --
   16.0        --        -8.5          --          --          --
   20.0        --        -6.2          --          --          --
   25.0        --        -4.4          --          --          --
   31.5        --        -3.0          --          --          --
   40.0        --        -2.0          --          --          --
   50.0       61.5       -1.3         6.02     .104+07       .001
   63.0       62.5        -.8         6.17     .147+07       .001
   80.0       63.5        -.5         6.30     .198+07       .002
  100.0       64.5        -.3         6.42     .261+07       .002
  125.0       65.5        -.2         6.53     .337+07       .003
  160.0       66.5        -.1         6.64     .434+07       .004
  200.0       67.5         .0         6.75     .558+07       .005
  250.0       68.5         .0         6.85     .703+07       .006
  315.0       69.5         .0         6.95     .885+07       .008
  400.0       70.5         .0         7.05     .111+08       .010
  500.0       71.5         .0         7.15     .140+08       .013
  630.0       72.5         .0         7.25     .177+08       .016
  800.0       73.5         .0         7.35     .222+08       .020
 1000.0       74.5         .0         7.45     .280+08       .025
 1250.0       75.5         .0         7.55     .352+08       .032
 1600.0       76.5        -.1         7.64     .434+08       .039
 2000.0       77.5        -.2         7.73     .533+08       .048
 2500.0       78.5        -.3         7.82     .656+08       .059
 3150.0       79.5        -.5         7.90     .789+08       .071
 4000.0       80.5        -.8         7.97     .927+08       .083
 5000.0       81.5       -1.3         8.02     .104+09       .093
 6300.0       82.5       -2.0         8.05     .111+09       .100
 8000.0       83.5       -3.0         8.05     .111+09       .100
10000.0       84.5       -4.4         8.01     .102+09       .091
12500.0       85.5       -6.2         7.93     .845+08       .076
16000.0       86.5       -8.5         7.80     .627+08       .056
20000.0       87.5      -11.2         7.63     .424+08       .038

SUM Y                                          .112+10

DB(C) = 10 LOG(SUM Y)                           90.5
```

```
STEVENS SONES, PHONS, FROM OCTAVE BAND LEVELS

+3 DB/OCTAVE SLOPE (WHITE NOISE)

                         FREQUENCY  SIGNAL  LOUDNESS
                                    LEVEL   INDEX

                            HZ        DB      --

                            63.0     67.3      3.0
                           125.0     70.3      5.2
                           250.0     73.3      7.4
                           500.0     76.3     10.5
                          1000.0     79.3     15.3
                          2000.0     82.3     23.0
                          4000.0     85.3     35.3
                          8000.0     88.3     56.0
                         16000.0     91.3     33.0

SUM OF LOUDNESS INDICES                      188.7
SUBTRACT MAXIMUM LOUDNESS INDEX             - 56.0

                                             132.7
MULTIPLY BY .3                              X   .3


                                              39.8
ADD MAXIMUM LOUDNESS INDEX                  + 56.0

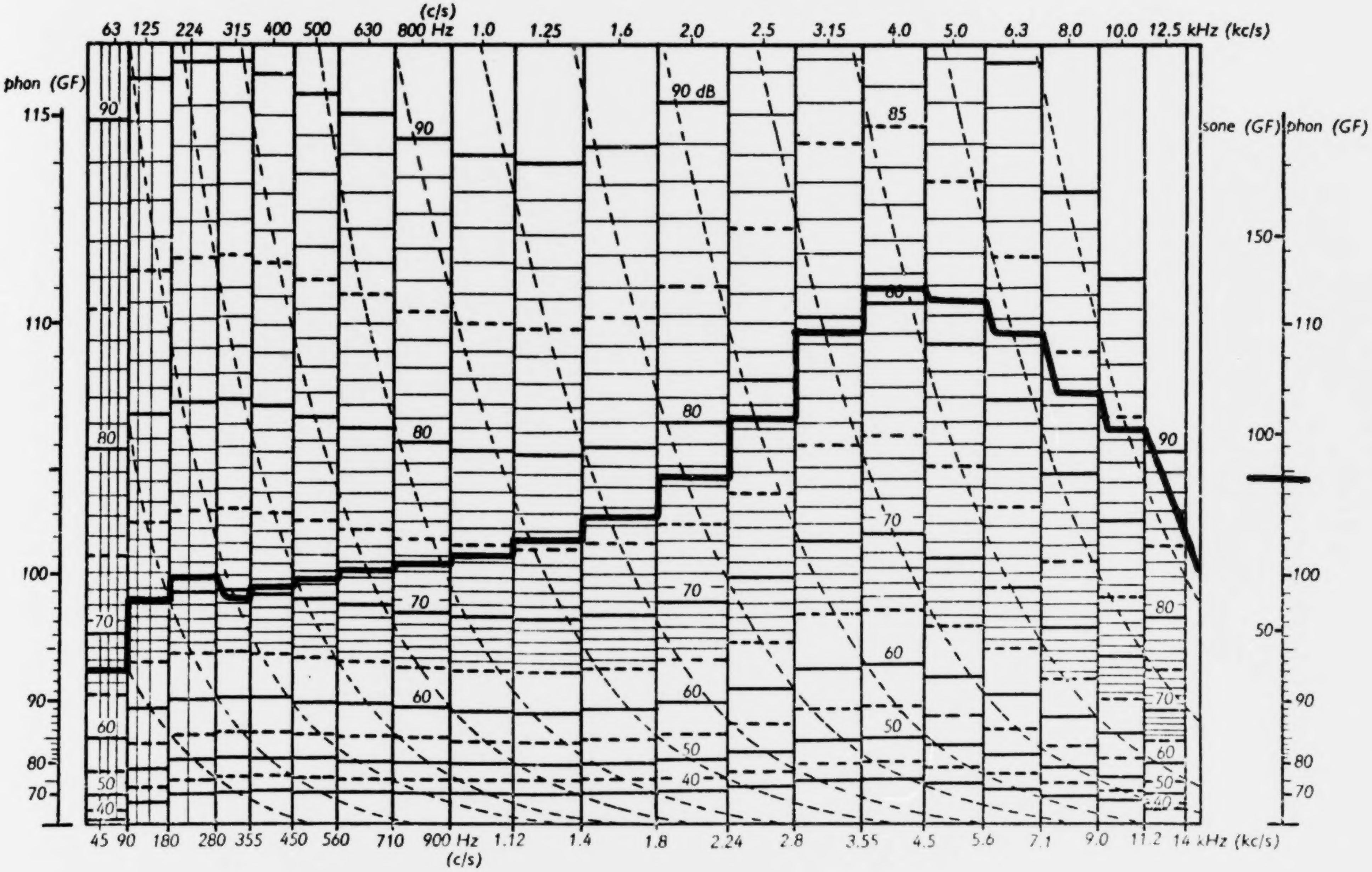
SONES                                         95.8

LOG2 SONES = (LOG10 SONES)/.301               6.58
                                            X 10.
MULTIPLY BY 10.
                                              65.8
ADD 40.                                     + 40.

PHONS                                        105.8
```

NOT REPRODUCIBLE

Zwicker sones, phons, from 1/3 octave bands
+3 dB/Octave Slope -- 104.7 Phons



```
KRYTER PERCEIVED NOISE LEVEL FROM 1/3 OCTAVE BANDS

+3 DB/OCTAVE SLOPE (WHITE NOISE)

                  FREQUENCY  SIGNAL  PERCEIVED
                             LEVEL   NOISINESS

                     HZ        DB       NOYS

                    50.0      61.5        .0
                    63.0      62.5       1.3
                    80.0      63.5       1.9
                   100.0      64.5       2.6
                   125.0      65.5       3.2
                   160.0      66.5       4.1
                   200.0      67.5       5.2
                   250.0      68.5       6.1
                   315.0      69.5       7.0
                   400.0      70.5       8.3
                   500.0      71.5       8.9
                   630.0      72.5       9.5
                   800.0      73.5      10.2
                  1000.0      74.5      10.9
                  1250.0      75.5      13.4
                  1600.0      76.5      18.7
                  2000.0      77.5      23.0
                  2500.0      78.5      28.3
                  3150.0      79.5      32.5
                  4000.0      80.5      34.8
                  5000.0      81.5      34.8
                  6300.0      82.5      34.8
                  8000.0      83.5      30.3
                 10000.0      84.5      26.4

SUM OF NOY VALUES                      356.4
SUBTRACT MAXIMUM NOY VALUE           - 34.8

                                       321.6
MULTIPLY BY .15                      X   .15

                                        48.2
ADD MAXIMUM NOY VALUE                + 34.8

N                                       83.1

LOG N                                   1.92
MULTIPLY BY 33.3                     X33.3

                                        63.9
ADD 40.                              + 40.

PERCEIVED NOISE LEVEL, PNL             103.9

ADD TONE CORRECTION                  +   .0
TONE CORRECTED PERCEIVED
NOISE LEVEL,PNLT                       103.9
```

```
+6 DB/OCTAVE SLOPE



                                                           SQUARED     RELATIVE
FREQUENCY    SIGNAL           DB(L)       WEIGHTED      PRESSURE    CONTRIBUTION
             LEVEL, L       WEIGHT, W     LEVEL, X      RATIO, Y       OF Y

   HZ           DB             DB           BEL            --           --


   10.0         --             --           --             --           --
   12.5         --             --           --             --           --
   16.0         --             --           --             --           --
   20.0         --             --           --             --           --
   25.0         --             --           --             --           --
   31.5         --             --           --             --           --
   40.0         --             --           --             --           --
   50.0        38.0            --          3.80         .631+04       .000
   63.0        40.0            --          4.00         .100+05       .000
   80.0        42.0            --          4.20         .158+05       .000
  100.0        44.0            --          4.40         .251+05       .000
  125.0        46.0            --          4.60         .398+05       .000
  160.0        48.0            --          4.80         .631+05       .000
  200.0        50.0            --          5.00         .100+06       .000
  250.0        52.0            --          5.20         .158+06       .000
  315.0        54.0            --          5.40         .251+06       .000
  400.0        56.0            --          5.60         .398+06       .000
  500.0        58.0            --          5.80         .631+06       .000
  630.0        60.0            --          6.00         .100+07       .000
  800.0        62.0            --          6.20         .158+07       .001
 1000.0        64.0            --          6.40         .251+07       .001
 1250.0        66.0            --          6.60         .398+07       .001
 1600.0        68.0            --          6.80         .631+07       .002
 2000.0        70.0            --          7.00         .100+08       .004
 2500.0        72.0            --          7.20         .158+08       .006
 3150.0        74.0            --          7.40         .251+08       .009
 4000.0        76.0            --          7.60         .398+08       .015
 5000.0        78.0            --          7.80         .631+08       .023
 6300.0        80.0            --          8.00         .100+09       .037
 8000.0        82.0            --          8.20         .158+09       .058
10000.0        84.0            --          8.40         .251+09       .093
12500.0        86.0            --          8.60         .398+09       .147
16000.0        88.0            --          8.80         .631+09       .233
20000.0        90.0            --          9.00         .100+10       .369

SUM Y                                                   .271+10

DB(L) = 10 LOG(SUM Y)                                    94.3
```

NOT REPRODUCIBLE

```
+6 DB/OCTAVE SLOPE



                                                    SQUARED    RELATIVE
FREQUENCY   SIGNAL     DB(A)      WEIGHTED   PRESSURE   CONTRIBUTION
            LEVEL, L   WEIGHT, W  LEVEL, X   RATIO, Y     OF Y

   HZ          DB         DB         BEL         --          --


   10.0        --       -70.4        --          --          --
   12.5        --       -63.4        --          --          --
   16.0        --       -56.7        --          --          --
   20.0        --       -50.5        --          --          --
   25.0        --       -44.7        --          --          --
   31.5        --       -39.4        --          --          --
   40.0        --       -34.6        --          --          --
   50.0       38.0      -30.2        .78      .603+01       .000
   63.0       40.0      -26.2       1.38      .240+02       .000
   80.0       42.0      -22.5       1.95      .891+02       .000
  100.0       44.0      -19.1       2.49      .309+03       .000
  125.0       46.0      -16.1       2.99      .977+03       .000
  160.0       48.0      -13.4       3.46      .288+04       .000
  200.0       50.0      -10.9       3.91      .813+04       .000
  250.0       52.0       -8.6       4.34      .219+05       .000
  315.0       54.0       -6.6       4.74      .550+05       .000
  400.0       56.0       -4.8       5.12      .132+06       .000
  500.0       58.0       -3.2       5.48      .302+06       .000
  630.0       60.0       -1.9       5.81      .646+06       .001
  800.0       62.0        -.8       6.12      .132+07       .001
 1000.0       64.0         .0       6.40      .251+07       .003
 1250.0       66.0         .6       6.66      .457+07       .005
 1600.0       68.0        1.0       6.90      .794+07       .008
 2000.0       70.0        1.2       7.12      .132+08       .014
 2500.0       72.0        1.3       7.33      .214+08       .022
 3150.0       74.0        1.2       7.52      .331+08       .034
 4000.0       76.0        1.0       7.70      .501+08       .052
 5000.0       78.0         .5       7.85      .708+08       .073
 6300.0       80.0        -.1       7.99      .977+08       .101
 8000.0       82.0       -1.1       8.09      .123+09       .127
10000.0       84.0       -2.5       8.15      .141+09       .145
12500.0       86.0       -4.3       8.17      .148+09       .152
16000.0       88.0       -6.6       8.14      .138+09       .142
20000.0       90.0       -9.3       8.07      .117+09       .121

SUM Y                                         .972+09

DB(A) = 10 LOG(SUM Y)                          89.9
```

```
+6 DB/OCTAVE SLOPE


                                                         SQUARED    RELATIVE
FREQUENCY   SIGNAL        DB(B)      WEIGHTED   PRESSURE   CONTRIBUTION
            LEVEL, L    WEIGHT, W    LEVEL, X   RATIO, Y     OF Y

   HZ          DB          DB          BEL         --          --


   10.0        --        -38.2         --          --          --
   12.5        --        -33.2         --          --          --
   16.0        --        -28.5         --          --          --
   20.0        --        -24.2         --          --          --
   25.0        --        -20.4         --          --          --
   31.5        --        -17.1         --          --          --
   40.0        --        -14.2         --          --          --
   50.0       38.0       -11.6        2.64     .437+03       .000
   63.0       40.0        -9.3        3.07     .117+04       .000
   80.0       42.0        -7.4        3.46     .288+04       .000
  100.0       44.0        -5.6        3.84     .692+04       .000
  125.0       46.0        -4.2        4.18     .151+05       .000
  160.0       48.0        -3.0        4.50     .316+05       .000
  200.0       50.0        -2.0        4.80     .631+05       .000
  250.0       52.0        -1.3        5.07     .117+06       .000
  315.0       54.0         -.8        5.32     .209+06       .000
  400.0       56.0         -.5        5.55     .355+06       .001
  500.0       58.0         -.3        5.77     .589+06       .001
  630.0       60.0         -.1        5.99     .977+06       .001
  800.0       62.0          .0        6.20     .158+07       .002
 1000.0       64.0          .0        6.40     .251+07       .004
 1250.0       66.0          .0        6.60     .398+07       .006
 1600.0       68.0          .0        6.80     .631+07       .010
 2000.0       70.0         -.1        6.99     .977+07       .015
 2500.0       72.0         -.2        7.18     .151+08       .023
 3150.0       74.0         -.4        7.36     .229+08       .035
 4000.0       76.0         -.7        7.53     .339+08       .052
 5000.0       78.0        -1.2        7.68     .479+08       .073
 6300.0       80.0        -1.9        7.81     .646+08       .099
 8000.0       82.0        -2.9        7.91     .813+08       .125
10000.0       84.0        -4.3        7.97     .933+08       .143
12500.0       86.0        -6.1        7.99     .977+08       .150
16000.0       88.0        -8.4        7.96     .912+08       .140
20000.0       90.0       -11.1        7.89     .776+08       .119

SUM Y                                          .652+09

DB(B) = 10 LOG(SUM Y)                          88.1
```

+6 DB/OCTAVE SLOPE

FREQUENCY	SIGNAL LEVEL, L	DB(C) WEIGHT, W	WEIGHTED LEVEL, X	SQUARED PRESSURE RATIO, Y	RELATIVE CONTRIBUTION OF Y
HZ	DB	DB	BEL	--	--
10.0	--	-14.3	--	--	--
12.5	--	-11.2	--	--	--
16.0	--	-8.5	--	--	--
20.0	--	-6.2	--	--	--
25.0	--	-4.4	--	--	--
31.5	--	-3.0	--	--	--
40.0	--	-2.0	--	--	--
50.0	38.0	-1.3	3.67	.468+04	.000
63.0	40.0	-.8	3.92	.832+04	.000
80.0	42.0	-.5	4.15	.141+05	.000
100.0	44.0	-.3	4.37	.234+05	.000
125.0	46.0	-.2	4.58	.380+05	.000
160.0	48.0	-.1	4.79	.617+05	.000
200.0	50.0	.0	5.00	.100+06	.000
250.0	52.0	.0	5.20	.158+06	.000
315.0	54.0	.0	5.40	.251+06	.000
400.0	56.0	.0	5.60	.398+06	.001
500.0	58.0	.0	5.80	.631+06	.001
630.0	60.0	.0	6.00	.100+07	.002
800.0	62.0	.0	6.20	.158+07	.002
1000.0	64.0	.0	6.40	.251+07	.004
1250.0	66.0	.0	6.60	.398+07	.006
1600.0	68.0	-.1	6.79	.617+07	.010
2000.0	70.0	-.2	6.98	.955+07	.015
2500.0	72.0	-.3	7.17	.148+08	.023
3150.0	74.0	-.5	7.35	.224+08	.035
4000.0	76.0	-.8	7.52	.331+08	.052
5000.0	78.0	-1.3	7.67	.468+08	.073
6300.0	80.0	-2.0	7.80	.631+08	.099
8000.0	82.0	-3.0	7.90	.794+08	.125
10000.0	84.0	-4.4	7.96	.912+08	.143
12500.0	86.0	-6.2	7.98	.955+08	.150
16000.0	88.0	-8.5	7.95	.891+08	.140
20000.0	90.0	-11.2	7.88	.759+08	.119
SUM Y				.638+09	
DB(C) = 10 LOG(SUM Y)				88.0	

```
STEVENS SONES, PHONS, FROM OCTAVE BAND LEVELS

+6 DB/OCTAVE SLOPE

                  FREQUENCY  SIGNAL  LOUDNESS
                             LEVEL   INDEX

                      HZ       DB      --

                     63.0     45.1       .4
                    125.0     51.1      1.3
                    250.0     57.1      2.8
                    500.0     63.1      4.9
                   1000.0     69.1      8.3
                   2000.0     75.1     14.4
                   4000.0     81.1     26.5
                   8000.0     87.1     52.0
                  16000.0     93.1     38.0

SUM OF LOUDNESS INDICES               148.7
SUBTRACT MAXIMUM LOUDNESS INDEX      - 52.0

                                       96.7
MULTIPLY BY .3                       X   .3

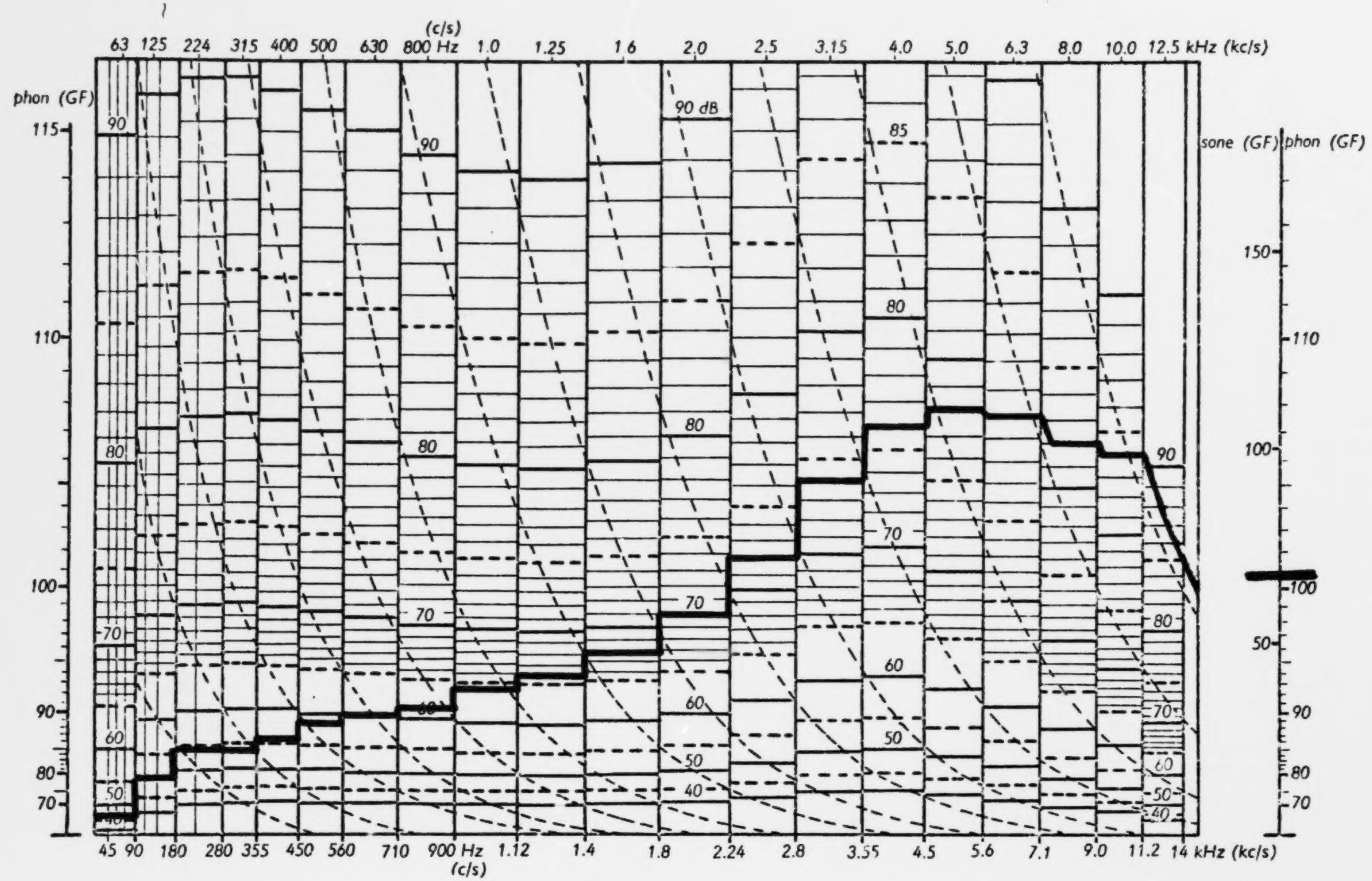
                                       29.0
ADD MAXIMUM LOUDNESS INDEX           + 52.0

SONES                                  81.0

LOG2 SONES = (LOG10 SONES)/.301        6.34
                                     X 10.
MULTIPLY BY 10.
                                       63.4
ADD 40.                              + 40.

PHONS                                 103.4
```

Zwicker sones, phons, from 1/3 octave bands
+6 dB/Octave Slope -- 101.0 Phons



```
KRYTER PERCEIVED NOISE LEVEL FROM 1/3 OCTAVE BANDS

+6 DB/OCTAVE SLOPE

               FREQUENCY  SIGNAL  PERCEIVED
                          LEVEL   NOISINESS

                   HZ       DB       NOYS

                  50.0     38.0        .0
                  63.0     40.0        .0
                  80.0     42.0        .0
                 100.0     44.0        .0
                 125.0     46.0        .0
                 160.0     48.0       1.0
                 200.0     50.0       1.4
                 250.0     52.0       1.8
                 315.0     54.0       2.3
                 400.0     56.0       3.0
                 500.0     58.0       3.5
                 630.0     60.0       4.0
                 800.0     62.0       4.6
                1000.0     64.0       5.3
                1250.0     66.0       7.0
                1600.0     68.0      10.4
                2000.0     70.0      13.8
                2500.0     72.0      18.1
                3150.0     74.0      22.3
                4000.0     76.0      25.6
                5000.0     78.0      27.4
                6300.0     80.0      29.4
                8000.0     82.0      27.4
               10000.0     84.0      25.6

SUM OF NOY VALUES                   233.9
SUBTRACT MAXIMUM NOY VALUE         - 29.4

                                    204.5
MULTIPLY BY .15                    X   .15

                                     30.7
ADD MAXIMUM NOY VALUE              + 29.4

N                                    60.1

LOG N                                1.78
MULTIPLY BY 33.3                   X33.3

                                     59.2
ADD 40.                            + 40.

PERCEIVED NOISE LEVEL, PNL           99.2

ADD TONE CORRECTION                +   .0
TONE CORRECTED PERCEIVED
NOISE LEVEL,PNLT                     99.2
```

Appendix E. Addresses of Standards Organizations and Associations.

1. American National Standards Institute
   1430 Broadway
   New York, New York 10018

2. American Society for Testing and Materials
   1916 Race Street
   Philadelphia, Pennsylvania 19103

3. Society of Automotive Engineers
   Two Pennsylvania Plaza
   New York, New York 10001

4. Institute of Electrical and Electronic Engineers
   345 East 47th Street
   New York, New York 10017

5. American Society of Heating, Refrigerating and Air-Conditioning Engineers
   United Engineering Center
   345 East 47th Street
   New York, New York 10017

6. Air-Conditioning and Refrigeration Institute
   1815 North Fort Myer Drive
   Arlington, Virginia 22209

7. Air Moving and Conditioning Association
   30 W. University Drive
   Arlington Heights, Illinois 60004

8. Air Diffusion Council
   435 North Michigan Avenue
   Chicago, Illinois 60611

9. Home Ventilating Institute
   1108 Standard Building
   Cleveland, Ohio 44113

10. Association of Home Appliance Manufacturers
    20 North Wacker Drive
    Chicago, Illinois 60606

11. National School Supply and Equipment Association
    Folding Partition Subsection
    27 East Monroe Street
    Chicago, Illinois 60603

12. California Redwood Association
617 Montgomery Street
San Francisco 11, California

13. Factory Mutual Engineering Division
184 High Street
Boston, Massachusetts 02110

14. Federal Specifications
Specification Sales (3FRDS)
Building 197, Washington Navy Yard
General Services Administration
Washington, D.C. 20407

15. American Boat and Yacht Council
15 East 26th Street
New York, New York 10010

16. Radio Manufacturers Association
1317 F Street, N. W.
Washington, D.C. 20004

17. Compressed Air and Gas Institute
122 East 42nd Street
New York, New York 10017

18. American Gear Manufacturers Association
1330 Massachusetts Avenue, N.W.
Washington, D.C. 20005

19. National Electrical Manufacturers Association
155 East 44th Street
New York, New York 10017

20. National Machine Tool Builders Association
2139 Wisconsin Avenue
Washington, D.C. 20007

21. Power Saw Manufacturers Association
734 15th Street, N.W.
Washington, D.C. 20005

22. Anti-Friction Bearing Manufacturers Association
60 East 42nd Street
New York, New York 10017

23. Hearing Aid Industry Conference, Inc.
75 East Wacher Drive
Chicago, Illinois 60001

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